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Environmental Impact Guidelines for New Source Underground Coal Mines and Coal Cleaning Facilities

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16. ABSTRACT

This guideline document has been prepared to augment the information previously released by the Office of Federal Activities entitled Environmental Impact Assessment Guidelines for Selected New Source Industries. Its purpose is to provide guidance for the preparation and/or review of environmental documents (Environmental Information Document or Environmental Impact Statement) which EPA may require under the authority of the National Environmental Policy Act (NEPA) as part of the new source (NPDES) permit application review process.

This document has been prepared in seven sections, organized in a manner to facilitate analysis of the various facets of the environmental review process. The initial section includes a broad overview of the industry intended to familiarize the audience with the processes, trends, impacts and applicable pollution regulations commonly encountered in the underground coal mining and coal cleaning industry. Succeeding sections provide a comprehensive identification and analysis of potential environmental impacts, pollution control technologies available to meet Federal standards, and other controlable impacts. The document concludes with three sections: available alternatives, a listing of Federal regulations (other than pollution control) which may apply to the new source applicant, and a comprehensive listing of references for further reading.

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EPA Task Officer:
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US Environmental Protection Agency
Office of Federal Activities
Washington, D.C. 20460

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Preface

This document is one of a series of industry-specific Environmental Impact Guidelines being developed by the Office of Federal Activities (OFA) for use in EPA's Environmental Impact Statement preparation program for new source NPDES permits. It is to be used in conjunction with Environmental Impact Assessment Guidelines for Selected New Source Industries, an OFA publication that includes a description of impacts common to most industrial sources.

The requirement for Federal agencies to assess the environmental impacts of their proposed actions is included in Section 102 of the National Environmental Policy Act of 1969 (NEPA), as amended. The stipulation that EPA's issuance of a new source NPDES permit as an action subject to NEPA is in Section 511(c)(1) of the Clean Water Act of 1977. EPA's regulations for preparation of Environmental Impact Statements are in Part 6 of Title 40 of the Code of Federal Regulations; new source requirements are in Subpart F of that Part.

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INTRODUCTION

The Clean Water Act (CWA; 33 USC 1251 et seq.) requires that USEPA establish standards of performance for categories of new source industrial wastewater discharges. Before the discharge of any pollutant to the navigable waters of the United States (US) can take place from a new source in an industrial category for which performance standards have been established, a new source National Pollutant Discharge Elimination System (NPDES) permit must be obtained from either the USEPA or the State (whichever is the administering authority for the State in which the discharge is proposed). Section 511(c)(1) of CWA requires that the issuance of NPDES permits by the USEPA for proposed new source discharges be subject to the review provisions of the National Environmental Policy Act (NEPA; 42 USC 4321 et seq.). During his NEPA review, the USEPA Regional Administrator may require the preparation of an Environmental Impact Statement (EIS) on the new source. The procedure established by the USEPA regulations (40 CFR 6 Subpart F) for applying NEPA to the issuance of new source NPDES permits, in turn, may require preparation of an Environmental Information Document (EID) by the permit applicant. Each EID is submitted to USEPA for review to determine whether potentially significant effects on the quality of the human environment will result from construction and operation of the new source. If significant potential impacts are identified, succinct draft and final EIS's describing the significant adverse effects and focusing on the key issues such as alternative measures to avoid and/or mitigate adverse effects are published by USEPA before issuing or denying the permit, in accordance with the overall NEPA regulations of the Council on Environmental Quality (43 FR 230:55978-56007; 29 November 1978).

These guidelines supplement the more general USEPA document, Environmental Impact Assessment Guidelines for Selected New Source Industries, which provides general guidance for preparing an EID and presents the impact assessment considerations that are common to most industries. Both that document and these guidelines should be used for development of EID's for new source underground coal mines and coal cleaning facilities.

These guidelines identify the environmental impacts that potentially result from the construction, operation, and abandonment of underground coal mines and coal cleaning plants. This volume is intended to assist USEPA personnel in the identification of those impact areas that should be addressed in every EID. In addition, these guidelines present (in Section 1): an overall description of the industry; principal mining areas and methods; environmental problems; and recent trends in new mine locations, raw materials, mining methods, pollution control techniques, and demand for industry output.

The remainder of this guidelines document consists of five sections. Section 2 discusses mining-related wastes and the impacts that may occur during construction, operation, and abandonment of coal mining facilities. Section 3 describes the technology for controlling adverse environmental impacts. Section 4 discusses other impacts that can be mitigated through design considerations and proper site and mine planning. Section 5 discusses the consideration and impact assessment of possible alternatives to proposed new source coal mining activities. Section 6 lists Federal legislation other than CWA that may apply to the coal mining industry. Section 7 provides a bibliography of literature that pertains to underground coal mines and coal cleaning facilities.

This document may be transmitted to permit applicants for informational purposes, but it should not be construed as outlining the complete procedural requirements for obtaining an NPDES permit, for complying with regulations promulgated by the US Office of Surface Mining Reclamation and Enforcement (USOSM) of the US Department of the Interior (USDOI), or as comprehending an applicant's total responsibilities under the new source NPDES permit program. USEPA determines the content of each specific new source EID in accordance with its final regulations that implement NEPA for new source NPDES permitting activity (40 CFR 6.604 [b]). These guidelines do not supersede those regulations nor do they supplant any specific directive received by the applicant from the USEPA official who is responsible for implementing those regulations in individual cases.

1. OVERVIEW OF THE INDUSTRY

This section provides basic information on the extent of the Nation's coal reserves and the methods that are used to extract, clean, and transport coal from underground mines. The descriptions of processes are followed by a brief examination of the coal market and a summary of regulations administered by the USEPA and the USOSM that apply to underground coal mines and coal cleaning facilities.

1.1. SUBCATEGORIZATION

The basis for the USEPA subcategorization of the coal mining industry for regulatory purposes is explained in the development document for effluent limitations and new source performance standards (USEPA 1976e). Coal mining activity is subcategorized by type (surface mine, underground mine, or preparation plant), untreated discharge characteristics (acidic or alkaline), and mine size (Group A, B, or C based on anticipated annual production).

For the purpose of developing environmental impact guidelines, USEPA addresses surface coal mining separately from underground coal mining and includes coal preparation plants with underground mines. Surface and underground mining techniques are sufficiently different to preclude the use of a unified assessment document for both kinds of mines. Because mechanical coal preparation is applicable to 60% of underground-mined coal (USDOE 1978), many prospective operators of large new source underground mines will require environmental impact guidance from USEPA on coal preparation in addition to underground mining. Because only 25% of surface-mined coal is cleaned mechanically, however, the environmental guidelines for coal preparation plants will be of interest to fewer surface mine operators.

1.1.1. Wastewater

Wastewater generated by the coal mining industry is subcategorized by source (extraction, preparation, or storage activities) and chemical characteristics of wastewater (alkaline or acid/ferruginous drainage). Each subcategory is subject to separate effluent limitations (40 CFR 434; 44 FR 9:2586-2592, 12 January 1979). The established categories include:

- Acidic wastewater from coal preparation plants and associated areas
- Alkaline wastewater from coal preparation plants and associated areas
- Acid (ferruginous) mine drainage
- Alkaline mine drainage.

1.1.2. Production

To use its resources most effectively for environmental review of new source NPDES coal mining permit applications, USEPA established screening procedures based on the maximum annual design production tonnage specified in an applicant's NPDES permit application. Two groups of underground coal mines are recognized on the basis of production tonnages:[1]

- Group B includes underground mines with annual production of 90,719 MT (100,000 T) or greater. Group B mines are subject at the applicant's option either to a comprehensive environmental review as described in 40 CFR 6, Subpart F or to certification that the applicant is following USEPA's Best Practices guidelines.[2] Mines that certify to the use of Best Practices are subject to field audits and to reviews of mining plans prepared in compliance with Best Practices at the option of USEPA. An application that certifies to Best Practices may be subject to a comprehensive environmental review if preliminary evidence indicates that the proposed mine may produce a significant effect on the environment.

- Group C includes underground mines with anticipated peak annual production less than 90,719 MT (100,000 T). A mine in this category must submit brief, basic environmental data to USEPA. Based on a review of these data, USEPA may decide to conduct a comprehensive environmental review that would result in the preparation of a finding of no significant impact or an EIS.

1.2. PROCESSES

These guidelines are applicable to underground coal mining, to coal cleaning, and to the auxiliary operations that support these major processes. Underground extraction methods and coal cleaning processes are described in the detail necessary to support the discussions of trends (Section 1.3.3.), impact identification (Section 2), and pollution control (Section 3). Greater insight into the mechanics of underground mining and coal processing is available from the literature cited herein.

---

[1] Group A includes surface mines only.

[2] The Best Practices guidelines have not been published formally, but they are incorporated by reference in the final new source regulations. "Best Practices for New Source Surface and Underground Coal Mines" was issued in a 1 September 1977 memorandum to Regional Administrators that provides interim guidance on the application of NEPA to new source coal mines.

1.2.1. Major Processes

The gross characteristics of the coal resources of the Nation are highly variable both regionally and locally. Coal seams reflect their geologic histories through physical and chemical characteristics such as depth, inclination, rank, grade, sulfur content, and potential to produce environmentally harmful pollutants. The underground coal mining and cleaning techniques that currently are used by the US coal industry evolved in response to the variability of the coal resource.

The following discussion of major processes highlights the techniques that are common to underground coal mining and cleaning operations nationally. Local variations in mining techniques are common. Coal cleaning practices and characteristics of effluents can vary regionally. The processes of coal formation are described first, followed by separate discussions of underground mining techniques and coal cleaning operations.

1.2.1.1. Formation and Geographical Distribution of Coal

Coal is formed by the burial and compaction of organic debris that accumulates from the decay of plants and animals in marine and freshwater marshes. Numerous swamps and back bay deltas dotted the coastal areas of the inland seas that at various times covered much of the North American continent. Each coal seam represents an accumulation of organic swamp debris which later was buried by coarse-grained sediments from upland areas. The extent and longevity of each swamp determined the extent and thickness of individual coal seams.

Short-lived, rapid influxes of coarse-grained sediments to the coastal swamps buried the organic debris at frequent intervals. With continued burial and lithification over geologic time, these sediments became the shaly partings that split many coal seams. Streams occasionally eroded through the peat and sediment that filled the swamps, producing channel deposits that cause locally unstable mine roof conditions and want areas in some coal seams. Widespread upheaval and erosion removed entire seams from some regions' stratigraphy. Some coal seams were truncated abruptly by regional tilt and erosion. Many coal seams thin laterally to the feather edges that mark the limits of their depositional basins.

Following their deposition, coal seams were subjected to varying amounts of burial, compaction, and folding. The initial compaction of swamp debris produced peat. Progressively more intense compaction of peat formed the coal materials of successive ranks including lignite, subbituminous coal, bituminous coal, and anthracite (Table 1).

The post-depositional history of a coal seam determines its rank, which is a measure of the coal's percentage of fixed carbon. The rank of coal increases as its percentage of fixed carbon increases. High fixed carbon in turn reflects great depth of burial, heat of compaction, and dynamic stresses from structural activities during the ages since the organic material was laid down. The lower-ranked coals are classified on the basis of calorific heat content, expressed as kg cal per kg (or BTU per lb).

Table 1. Classification of coals by rank.

CLASS	RANK	LIMITS[1]
Anthracite	Metaanthracite	FC ≥ 98% VM ≤ 2%
	Anthracite	FC 92 - <98% VM 2 - <8%
	Semianthracite	FC 86 - <92% VM 8 - <14%
Bituminous	Low volatile Bituminous coal	FC 78 - <86% VM 14 - <22%
	Medium volatile Bituminous coal	FC 69 - <78% VM 22 - ≤31%
	High volatile A Bituminous coal	FC < 69% VM > 31% BTU ≥ 14,000
	High volatile B Bituminous coal	BTU 13,000 - 14,000
	High volatile C Bituminous coal	BTU 11,500 - <13,000
Subbituminous	Subbituminous A coal	BTU 10,500 - <11,500
	Subbituminous B coal	BTU 9,500 - <10,500
	Subbituminous C coal	BTU 8,300 - <9,500
Lignite	Lignite A	BTU 6,300 - <8,300
	Lignite B	BTU < 6,300

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[1] FC - percent by dry weight of fixed carbon
VM - percent by volume of volatile matter
BTU - British thermal units per pound of naturally moist coal

Source: Yancey, H.F. and M.R. Geer. 1968. Properties of coal and impurities in relation to preparation. In: Leonard, Joseph W. and David R. Mitchell. 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, 926 p.

Bituminous coal and anthracite are classified by their percentages of fixed carbon and volatile matter.

The chemical characteristics of coal seams relate directly to the depositional environments of individual swamps and the depth and duration of burial that resulted in heating and compaction of individual seams. The sulfur-bearing minerals, pyrite and marcasite, formed in the depositional environments that were associated with slowly subsiding delta plains and back bays (Horne and others 1978). Many coal seams and overburdens in the Eastern and Interior Coal Provinces were deposited in such environments, and consequently require special preparation and handling, if they are to be mined and abandoned without generating acid mine drainage. The depositional history of a coal seam determines its grade, which is a measure of its impurities. Grade increases as percentage of impurities decreases.

Two general analytical procedures provide data on the major and minor chemical constituents of coal. Proximate analysis yields an indirect determination of a coal's fixed carbon content by measuring the moisture content, percentage of ash, and percentage of total volatile matter. Ultimate analysis includes the determinations of carbon and hydrogen contents in coal by measuring their concentrations in the gases produced by the total combustion of the coal sample. Total sulfur, nitrogen, and ash are measured directly. Oxygen content is determined indirectly by comparing the cumulative weight of measured parameters with the original weight of the sample. Chlorine and phosphorus contents also may be determined. Standard tests for characterizing selected properties of coals are summarized in Table 2.

Percentages of fixed carbon and volatile matter generally are inversely proportional in coals of various rank (Table 1). Low volatility and high carbon content are among the chief attributes that create the valuable coking quality of metallurgical grade coals. During combustion, volatile matter usually is released as gases. Coal that contains a higher percentage of volatiles will yield less coke than an identical quantity of lower-volatile coal (Holway 1977). The calorific content of a coal, however, is not solely dependent on the relative proportions of fixed carbon and volatiles (Figure 1).

Metallurgical grade coals generally fulfill four basic requirements that expedite the coking process:

- Low ash -- Coals with greater than 8% ash require excessive amounts of carbon to volatilize the semicombustible material.

- Low sulfur -- Cokes from high sulfur coals require extra limestone to prevent the embrittlement of iron by sulfur during blast furnace operations.

Table 2. Summary of standard tests for the analysis of selected coal and coke properties.

ASTM Designation	Title
D 410	Sieve Analysis of Coal
D 431	Designating the Size of Coal From its Sieve Analysis
D 2013	Preparing Coal Samples For Analysis
D 2015	Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter
D 2234	Collection of a Gross Sample of Coal
D 3172	Proximate Analysis of Coal and Coke
D 3173	Moisture in the Analysis Sample of Coal and Coke
D 3174	Ash in the Analysis Sample of Coal and Coke
D 3175	Volatile Matter in the Analysis Sample of Coal and Coke
D 3176	Ultimate Analysis of Coal and Coke
D 3177	Total Sulfur in the Analysis Sample of Coal and Coke
D 3302	Total Moisture in Coal

Source: American Society for Testing And Materials. 1978. Annual book of ASTM standards: Part 26. Philadelphia PA, 906 p.

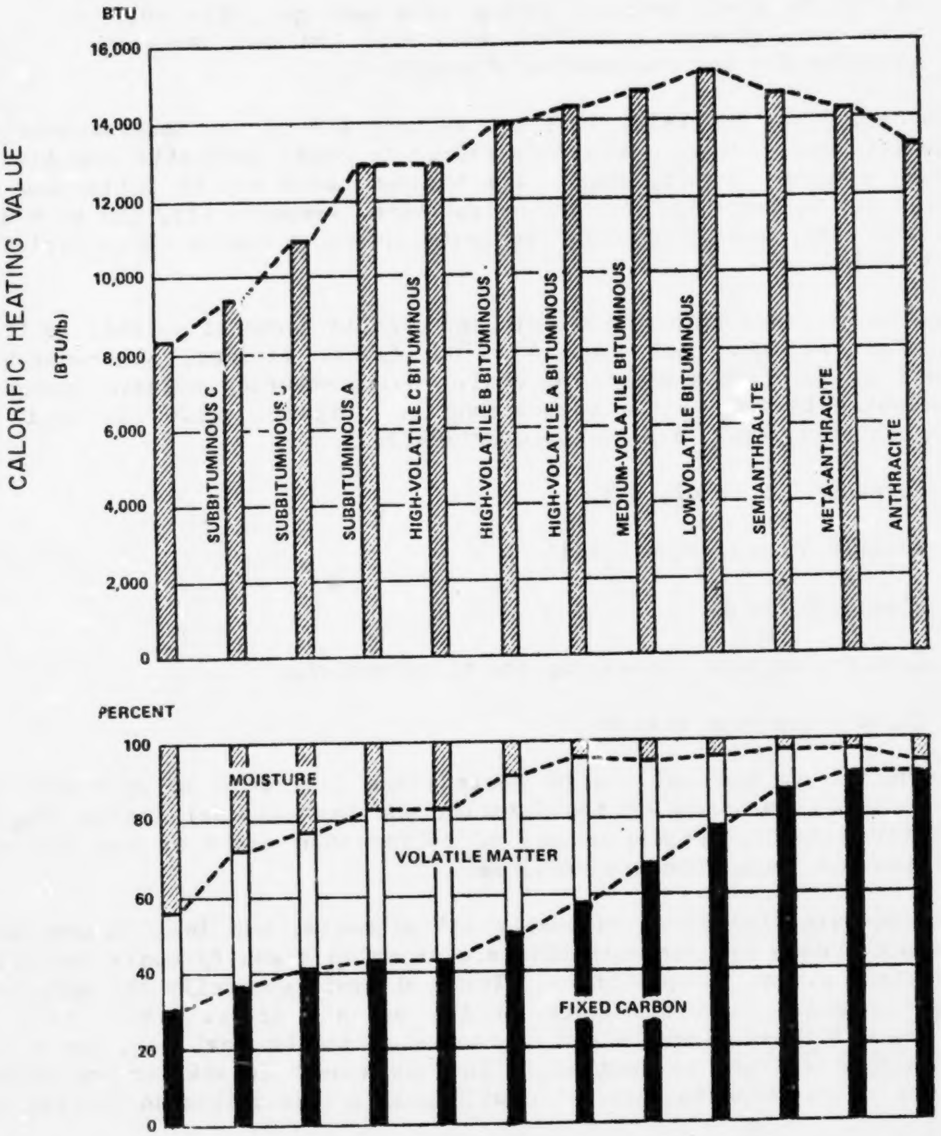


Figure 1. Calorific heating value and proportions of moisture, volatile matter, and fixed carbon contained in coals by rank. Leftmost column represents Lignite A.

Source: US Department of Energy. 1978b. International coal technology summary document. Office of Technical Programs Evaluation, HCP/p-3885, Washington DC, 178 p.

- Low coking pressure -- Coals may expand sufficiently during the coking process to damage coke-oven walls. Low volatile coals can expand significantly during coking, exerting up to 1.7 atm (10 psig) of pressure on oven walls.

- High coke strength -- Coke supports the limestone-iron ore charge in blast furnaces during iron making. High volatile coals generally produce cokes with low resistance to abrasion and low compressive strength.

One coal alone generally does not satisfy all of the requirements for high quality coking coal. Metallurgical-grade coals generally are blended to produce a higher quality coke. The blended coals may be pulverized and mixed with oil or water to increase or decrease, respectively, the bulk density of the coke, thus improving its strength and pressure characteristics (Leonard 1978).

Coal may contain both mineralogic and organic forms of sulfur. Sulfur-bearing minerals occur as crystals or as finely divided, semi-amorphous inclusions in the carbon matrix of coal. Sulfur-bearing organic compounds are chemically bonded to the carbon matrix. Organic sulfur in coal may occur in one of several forms (Gluskoter 1968):

- mercaptan or thiol, RSH

- sulfide or thio-ether, RSR'

- disulfide, RSSR'

- aromatic systems containing the thiophene ring

- delta-thiopyrone systems

The sulfur contents of the US coals range from 0.2% to approximately 7.0% by weight. The coals of the Interior and Eastern coal fields (Figure 2) generally have higher percentages of sulfur than coals of the Northern Great Plains and Rocky Mountain Provinces.

Coal contains traces of virtually all elements, but insufficient data on their occurrence and concentration are known to classify coals according to their trace element compositions. Trace elements generally are more concentrated in coals than elsewhere in the earth's crust. When coal is burned, most of these elements are concentrated in the coal ash, but a few are volatilized and can be emitted to the atmosphere (Gluskoter and others 1977). The trace elements associated with coal are described in Section 2.

The demonstrated reserve base of US coal and lignite includes 398 billion MT (438 billion T; USBOM 1977) distributed across six coal provinces in 37 states. The demonstrated reserve base refers to coal seams that currently are minable economically. The reserve base increases as new coal resources become minable economically with advances in technology or

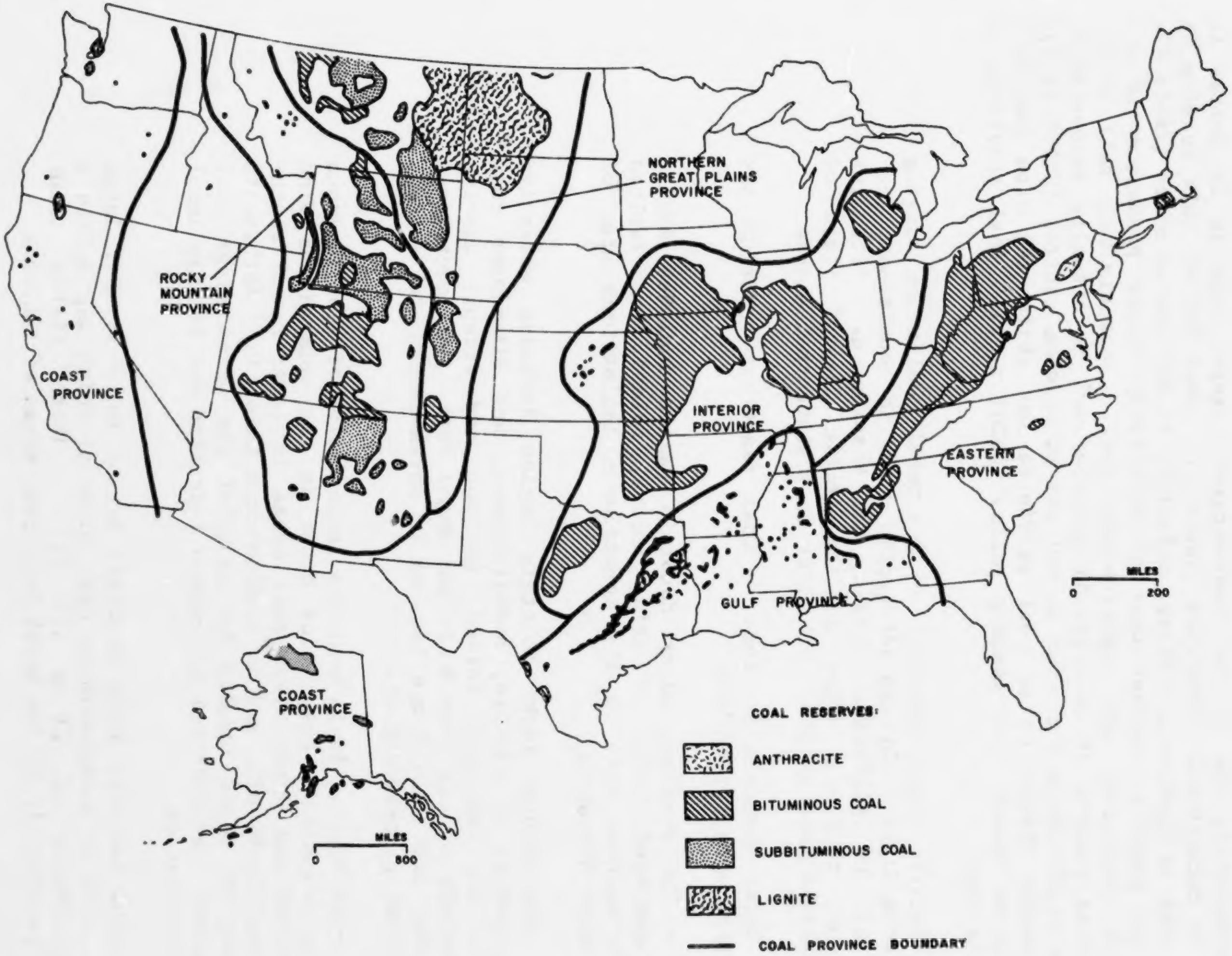

NORTHERN GREAT PLAINS PROVINCE
ROCKY MOUNTAIN PROVINCE
COAST PROVINCE
INTERIOR PROVINCE
EASTERN PROVINCE
GULF PROVINCE
COAST PROVINCE
MILES
0
200
MILES
0
800
COAL RESERVES:
ANTHRACITE
BITUMINOUS COAL
SUBBITUMINOUS COAL
LIGNITE
COAL PROVINCE BOUNDARY

Figure 2. Coal provinces and reserves of the United States.

Source: University of Oklahoma. 1975. Energy alternatives; a comparative analysis. Science and Public Policy Program, Norman OK, OY1-011-00025-Y, variously paged.

increases in the demand (price) for the coal. It decreases as the resources are extracted or the demand declines. Lignite reserves are considered to occur within 60 m (200 ft) of the surface. Other coal reserves occur within 300 m (1,000 ft). Subbituminous and lignite reserves are counted if they are at least 152 cm (60 in) thick. Higher rank reserves are at least 71 cm (28 in) thick.

Approximately 68% of the demonstrated reserve base in 26 States is minable by underground techniques (Table 3). Over 54% of this reserve is located east of Mississippi River, primarily in bituminous seams (Table 4). Underground minable reserves west of Mississippi River predominantly are low-sulfur (less than 1%), subbituminous coal. Approximately half of the demonstrated reserve of underground minable coal is actually recoverable, based on requirements for mine safety and subsidence control (USBOM 1977). The following discussion of coal provinces was abstracted from the 1975 Final EIS on Federal coal leasing policy (USDOI n.d.). Coal provinces of the US include:

- Pacific Coast Province -- Scattered coalfields ranging from lignite through anthracite occur in mountainous terrain in California, Oregon, and Washington. Extensive coal resources occur in the Arctic Coastal Plain of Alaska; scattered fields occur in southcentral Alaska

- Rocky Mountain Province -- Coal resources occur in six physiographic regions

  -- The Northern Rocky Mountain Region includes mostly scattered fields of thin, impure, folded, and faulted bituminous coal in the mountainous Yellowstone area of western Montana

  --The Middle Rocky Mountain Region includes extensive reserves of lignite, subbituminous, and bituminous coal in the complexly folded, faulted, and steeply dipping strata of Big Horn Basin and Hamms Fork, two mountainous coal areas which are located in northwestern and western Wyoming, respectively

  --The Wyoming Basin contains large fields of subbituminous to bituminous coal which occur in the mountainous Wind River and Green River coal areas in central and southwestern Wyoming and in northwestern Colorado. Anthracite may be found locally in parts of the Green River coal areas characterized by igneous intrusion and intense local deformation

  --The Southern Rocky Mountain Region holds several large fields of subbituminous coal in seams which may attain a thickness of 23 m (77 ft). These fields occur specifically in the North Park coal areas of Colorado

Table 3. Demonstrated coal reserve base of underground minable coal. Values are expressed in millions of metric tons.

	Coal Rank			Coal Province						
State	Anthracite	Bituminous	Sub-Bituminous	Pacific	Rocky Mountain	Great Plains	Interior	Gulf	Eastern	Total
Alabama		1,567.4						1,567.4		1,567.4
Alaska		560.9	4,369.0	4,928.7						4,928.7
Arkansas	80.6	148.3					228.9			228.9
Colorado	23.1	7,698.1	3,611.0		11,309.1[a]					11,309.1
Georgia		0.4							0.4	0.4
Illinois		48,298.3					48,298.3			48,298.3
Indiana		8,127.1					8,127.1			8,127.1
Idaho		4.0			4.0					4.0
Iowa		1,578.9					1,578.9			1,578.9
Kentucky		15,984.4					7,720.5		8,247.7	15,984.4
Maryland		830.7							830.7	830.7
Michigan		113.8					113.8			113.8
Missouri		1,289.2					1,289.2			1,289.2
Montana		1,259.4	63,248.6		64,508.0[a]					64,508.0
New Mexico	2.1	1,144.4	808.2		1,952.6					1,952.6
North Carolina		28.4							28.4	28.4
Ohio		11,900.4							11,900.4	11,900.4
Oklahoma		1,084.4					1,084.4			1,084.4
Oregon		b	13.2	13.2						13.2
Pennsylvania	6,333.4	20,305.4							26,638.8	26,638.8
Tennessee		570.2						570.2[a]		570.2
Utah		5,712.6	1.0		5,713.6					5,713.6
Virginia	125.0	2,979.8							3,104.1	3,104.1
Washington		232.1	759.4	991.5						991.5
West Virginia		30,415.8							30,415.8	30,415.8
Wyoming		3,638.6	25,131.6		28,770.2[a]					28,770.2
Total	6,564.2	165,472.3	97,941.9	5,933.4	59,963.9	52,293.7	68,457.3	1,852.5	81,451.4	269,952.1

[a] Combined reserve base of underground minable coal in two provinces.

[b] No reliable data on the reserve base of underground minable coal.

Source: US Bureau of Mines. August 1977. Demonstrated coal reserve base of the United States on January 1, 1976. US Department of the Interior, Washington DC, 8 p.

Table 4. Regional distribution of the demonstrated reserve base of underground minable coal (millions of metric tons).

	East of Mississippi River	West of Mississippi River	Total
Anthracite	6,458.4	105.8	6,564.2
Bituminous	141,121.6	24,350.7	165,472.3
Subbituminous	--	97,941.9	97,941.9
Total	147,580.0	122,398.4	269,978.4

Source: US Bureau of Mines. 1977. Demonstrated coal reserve base of the United States on January 1, 1976. US Department of the Interior, Washington DC, 8 p.

--The wide plateaus, uplifts, and broad basins of the Colorado Plateau Region include extensive reserves of subbituminous to anthracite coal in the Uinta, southwestern Utah, and San Juan River coal areas in Colorado, Utah, and northwestern New Mexico, respectively

--The Basin and Range Region is characterized by isolated, subparallel mountain ranges interspersed with nearly level, sediment-filled basins. Scattered fields of bituminous coal and limited reserves of anthracite coal seams up to 2 m (7 ft) thick are found in central and southern New Mexico within this Region

- Northern Great Plains Province -- The gently rolling plains, dissected plateaus, and isolated mountains of the five areas within the Northern Great Plains include extensive reserves of coal ranging in rank from lignite through semianthracite

-- The North-Central Region contains deposits of bituminous and subbituminous coal in the Judith River Basin and Assiniboine areas in Montana, respectively

--The Fort Union coal area, where lignite to subbituminous coals occur in Montana and North Dakota, comprises the largest single coal resource in the United States. The estimated lignite reserve (based on less restrictive criteria than are used to calculate the demonstrated reserve base) of this area exceeds 398 billion MT (438 billion T; University of Oklahoma 1975)

--The Powder River Basin includes reserves of subbituminous to bituminous coal in southern Montana and northeastern Wyoming

--Fields of subbituminous coal as well as extensive reserves of lignite are found in the 21,000 sq km (8,000 sq mi) Denver Coal Region of Colorado

--The Raton Mesa area in southern Colorado contains reserves of bituminous coal

- Interior Province -- Reserves of bituminous and semianthracite coal are found in the flatlands of the Midwestern States between the Appalachian Plateaus and the Rocky Mountains. The higher quality coal seams are located in the western part of the Province

- Gulf Coast Province -- Coal reserves in the lowlands and coastal regions of southern and eastern Texas and the Mississippi Valley include bituminous seams near the Mexican border and extensive deposits of lignite scattered from southern Texas to Alabama

- Eastern Coal Province -- Coal reserves occur in bands which trend northeast-southwest and parallel major structural features of the mountainous region that extends 1,300 km (800 mi) from northern Pennsylvania to northwestern Alabama. Coal rank generally decreases from anthracite to bituminous in a westerly direction across these bands.

1.2.1.2. Underground Mining Systems

Underground mining systems range in complexity from conventional drill-and-shoot operations to fully automated longwall systems. Summary discussions of mining systems (USDOE 1978; USEPA 1978, USEPA 1976d; USEPA 1975) and comprehensive texts (Cummins and Given 1973; Hittman Associates, Inc. 1976) are available which describe in detail the technical aspects of the development, operation, and abandonment of underground coal mines. The following description of underground mining systems uses the minimum level of detail necessary to identify the sources of potential environmental impact associated with underground coal mining.

A modern underground coal mine represents planning, development, and intensive capital investment for several years preceding the profitable production of coal from the mine. Underground mines are significantly more expensive to develop and operate than surface mines. Therefore they usually are planned for long-term operation in coal seams that are not recoverable economically by surface mining methods alone.

The underground coal mining process may be characterized as four operations:

- Planning
- Development
- Production
- Abandonment

i.2.1.2.1. Planning

Planning is fundamental to mine development. Permit applicants generally supply relatively complete plans and specifications to the relevant State regulatory agencies. Plans for underground mines should conform to the Federal Mine Safety and Health Act of 1977 (PL 95-164). Additionally, underground coal mines should be planned to avoid, minimize, or mitigate potential adverse environmental effects. This document generally describes the environmental considerations that are appropriate for the mine planning process. Additional guidance is available from the USEPA region to which the new source NPDES permit application is made.

1.2.1.2.2. Development

The development or construction of an entire underground coal mine may take decades, and extraction may commence in some parts of the mine years before development begins in others. In the ideal situation, entryways and crosscuts are advanced through the coal seam to the limits of the property to be mined. Coal then is extracted from pillars and longwalls in retreat (that is, in the direction opposite to the development advance).

Full development of the mine prior to production requires the long-term investment of considerable capital. Plans for mine development and extraction may change radically after mining commences, based on the availability of capital, innovative technology, and markets. The amount of salable coal produced during mine development may be minuscule compared to annual tonnages during full scale production.

Development of the mine generally begins with site layout, including the posting of signs and the installation of wastewater and runoff control measures as specified in the regulatory program administered by the US Office of Surface Mining (USOSM; 30 CFR Chapter VII, 42 FR 239:62639-62716, 13 December 1977). These regulations apply to underground mines with surface-disturbed areas greater than 0.8 ha (2.0 ac), and they specify the minimum standards of performance acceptable under the Surface Mining Control and Reclamation Act of 1977 (SMCRA; 30 USC 1201 *et seq.*).

Mine development generally includes a standard set of operations:

- Coal cutting machinery or conventional drill-and-blast techniques may be used to drive entryways through the coal seam. Entryways are interconnected with crosscuts, producing a honeycomb of unexcavated coal and voids

- Roof control systems are installed. Primary roof control is a function of the geometry of coal left in place during mine development. The configuration of entryways and crosscuts depends on the amount of subsidence permissible and the strength and thickness of the coal seam and overburden (Cummins and Given 1973; Hittman Associates, Inc. 1976). Bolts, props, trusses, shields, and other artificial roof support systems are used to prevent roof falls

- Ventilation, haulage, and electrical systems are installed. One function of the layout of pillars and barriers is to minimize the cost of providing adequate ventilation to all working areas of the mine. A minimum number of entryways and crosscuts also is necessary for

> rapid and efficient transport of coal from work areas. In coal mines staffed by members of the United Mine Workers of America (UMWA), electricity (traditionally direct current) fulfills all power requirements underground. Diesel equipment increasingly is being used in non-UMWA operations.

The pattern of crosscuts and entryways appropriate for an individual mine is determined on the basis of lithology of the overburden, safety requirements, conservation practices, and workspace needs underground. Mine openings range in width from 3.6 to 9 m (12 to 30 ft), based on depth and thickness of the seam, extraction ratios, roof conditions, and the number of independent support systems that are proposed for roof control. The 3.6 m minimum width is applicable to shallower seams. Access to the mine by most kinds of machinery is restricted by openings of widths less than 3.6 m. The maximum opening generally is 6.1 m (20 ft) wide where a single kind of roof support system is used, and 9 m wide where two kinds are used (Hittman Associates, Inc. 1976).

The distribution of compressive and tensile forces around a mine opening further constrains the geometry of mine development (Figure 3). The average stress to any horizon of interest for coal mining is 0.25 atm/m (1.1 psi/ft) of depth. The stress field has a nominal homogeneity, unless it is perturbed by an anomaly, such as a mine opening. Most of the forces depicted in Figure 3 are displaced toward the sides of the opening and bear on the unexcavated coal. The superimposed lateral compressive forces form an arc, called a pressure arch, that bears near the periphery of the opening. Bending and shearing forces in the roof are counterbalanced by artificial roof support systems.

To support the roof properly, a generally symmetric system of pillars, barriers, abutments, and ribs (Figure 4) remains unexcavated until the extraction phase commences. The dimensions and geometry of unexcavated features generally reflect their intended life spans and purposes, as well as the strengths and structural properties of the coal seam and overburden.

Given an opening of width W (Figure 5), the concentration of elastic (fracturing) stresses at the periphery of the opening may exceed the in situ stress near the center of the pillar by a factor of 5 to 7. This stress concentration may dissipate at a distance of 1 - 1/2 W into the pillar, or farther depending on the distribution of in situ plastic (yielding or flowing) stresses. Theoretically, a single coal pillar should be three times wider (3W) than the adjoining opening (Hittman Associates, Inc. 1976).

The pressure arch theory of entryway design accounts for the lateral transfer of overburden pressures to the peripheries of multiple openings. The diameter of the arch of lateral compressive forces located above an opening (Figure 3) increases in proportion to the width of the opening. A

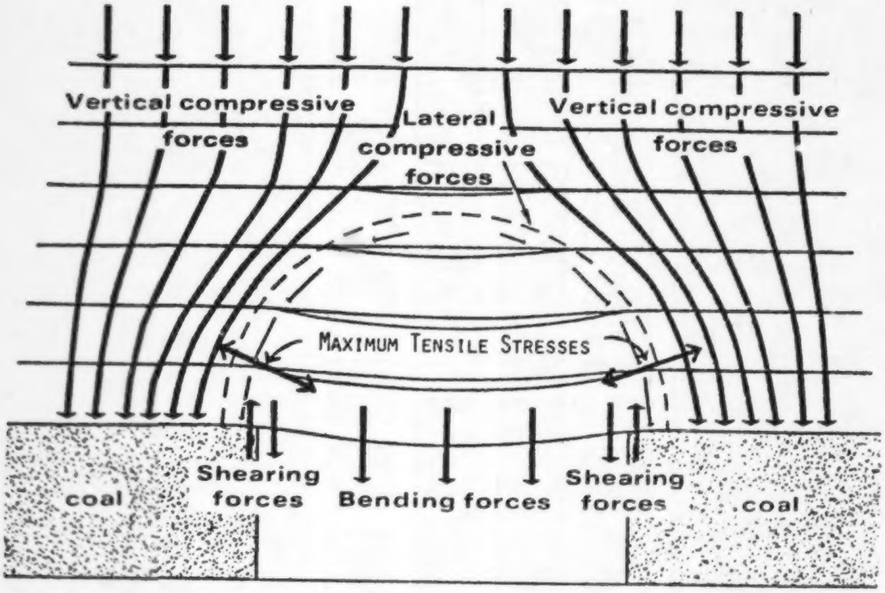

Vertical compressive forces
Lateral compressive forces
Vertical compressive forces
MAXIMUM TENSILE STRESSES
coal
Shearing forces
Bending forces
Shearing forces
coal

Figure 3. Distribution of forces around a narrow opening in a deep coal seam.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.

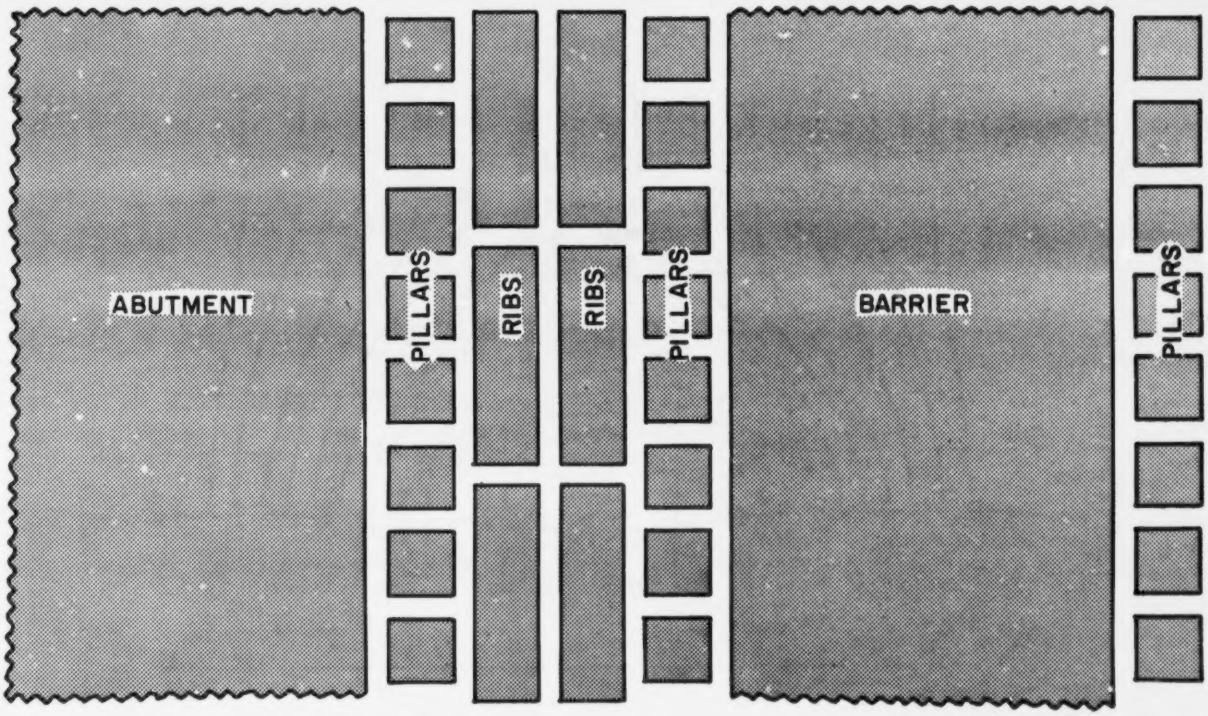

ABUTMENT
PILLARS
RIBS
RIBS
PILLARS
BARRIER
PILLARS

Figure 4. Nomenclature of geometries for unexcavated coal.

Source: Adapted from Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.

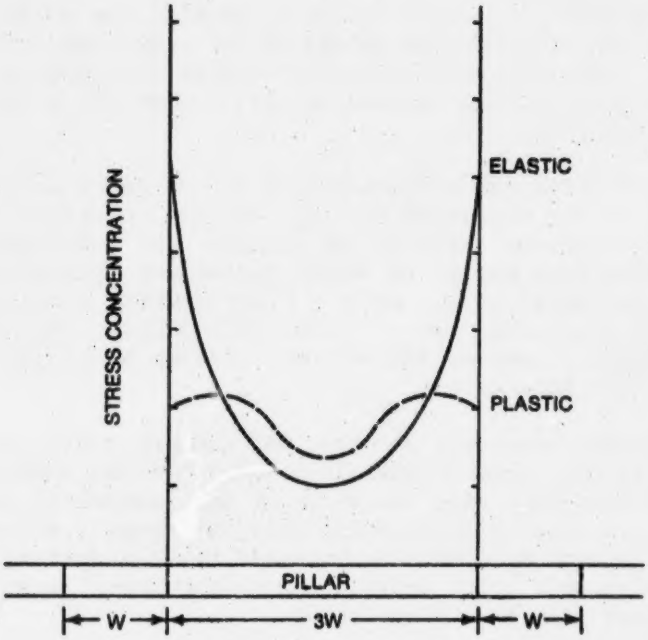


Figure 5. Concentrations of stresses in a coal pillar. The maximum stress concentration is located at the periphery of the pillar, which is 3 times wider than the adjacent openings.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.

limit (called the maximum pressure arch) eventually is reached at which failure of the roof is imminent.

To illustrate the function of the pressure arch theory, and as a prelude to a more general discussion of subsidence (Section 2.3.2.), the following example is given. For coal seams located at depths D between 120 and 600 m (400 and 2,000 ft), empirical evidence indicates that the width of the maximum pressure arch equals 0.15D + 60 where D is given in feet. Thus, for a set of standard conditions, (seam height, opening width, lithology, and structure) the maximum pressure arch in a coal seam 240 m (800 ft) deep is equal to 54 m (180 ft). As a factor of safety, the width across a series of ribs or pillars generally is chosen to be less than 75% of the maximum pressure arch. For this hypothetical example, the maximum span across a series of ribs and pillars should be less than 40 m (135 ft; Hittman Associates, Inc. 1976).

Dimensions of ribs and pillars depend on the depth and thickness of the seam, the width of the excavated opening, and the structure and lithology of the roof and overburden. Widths of pillars and ribs generally increase relative to widths of openings as depth increases. Widths of barriers generally excede the mean of the width of the maximum pressure arch and the width across the adjoining rows of ribs and pillars. For the hypothetical example at a depth of 240 m, the minimum barrier width is 47 m (157.5 ft; Hittman Associates, Inc. 1976).

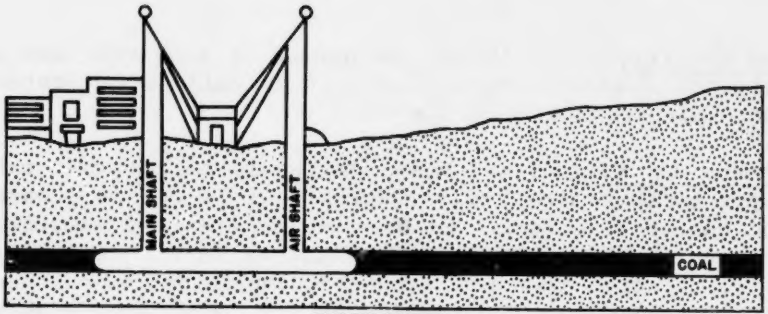
An underground mine may be reached through shaft, drift, or slope entryways (Figure 6). Shafts and slope entryways are driven through overburden to reach the coal seam where it is not exposed at an outcrop. The choice of vertical shaft versus slope entryway usually depends on the proposed size of the entryway and the proposed haulage system, as well as the ventilation system and other service considerations. A drift entryway is driven into a coal seam from its outcrop.

1.2.1.2.3. Extraction

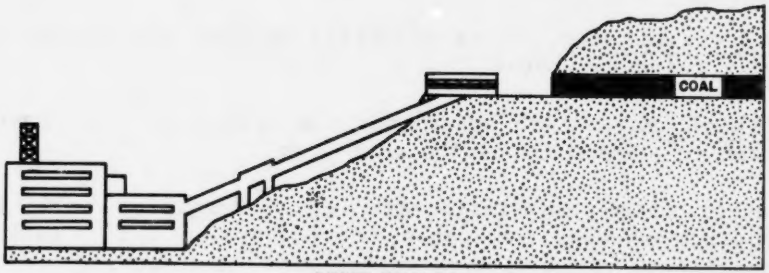
Coal is extracted during production either with conventional drill and shoot techniques or by continuous mining systems. Extraction systems for mine development and coal production are chosen based on the operator's experience, available capital, and the following coal seam variables:

- Seam height, which determines one economic basis for choosing a mining system. Conventional mining systems become less efficient as seam height or thickness increases. Longwall mining systems are impeded by variations in seam height

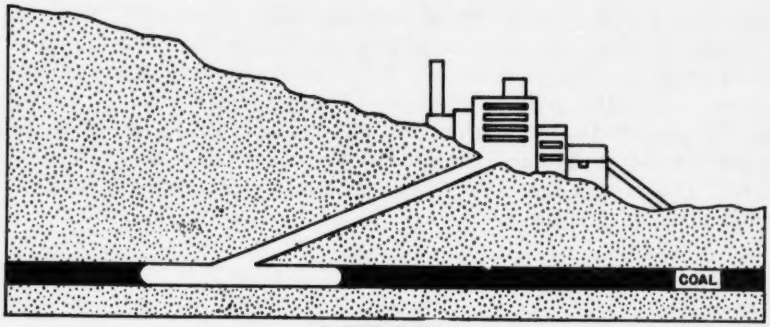
- Bottom quality, which ranges from excellent (dry, firm, and even) to poor (wet, soft, and pitted or rutted), and affects machine operations by limiting traction and restricting maneuverability



SHAFT ENTRY



DRIFT ENTRY



SLOPE ENTRY

Figure 6. Methods of entry to underground coal mines.

Source: US Environmental Protection Agency. 1975. Inactive and abandoned underground mines: water pollution prevention and control. US Environmental Protection Agency, Office of Water and Hazardous Materials, Washington DC, EPA-440/9-75-007, 339 p.

- Roof quality, which limits the amount of coal that may be extracted from the excavation without artificial protection against collapse of the mine roof

- Methane liberation, which in some seams occurs at a rate proportional to the rate at which coal is cut or sheared from the working face. Methane accumulates and sometimes ignites in underground workings when it is not removed by the ventilation system. Methane accumulation is monitored at least once every 20 minutes at the seam face, causing disruption of otherwise continuous work cycles

- Hardness of seam, which primarily affects the choice of coal cutting equipment

- Depth of seam, which determines the response of the overburden to excavation of the coal seam

- Water, which may infiltrate the underground workings through channels, fractures, fissures, or other water-transmitting voids in mine walls, roof, and bottom.

A comparison of manpower requirements and productivities of continuous and conventional mining systems appears in Table 5. Continuous mining systems generally employ fewer men per face and produce more tons per man and per shift than conventional systems. The efficiency of continuous mining systems remains essentially unchanged with increasing seam height. Conventional systems reach a point of diminishing return as seam height reaches 1.8 m (6 ft). These trends are illustrated in Figure 7, which is based on the data presented in Table 5.

Conventional mining systems utilize five categories of unit operations (Hittman Associates, Inc. 1976) which can proceed simultaneously at separate working faces (Figure 8). The categories include:

- Cutting a slit or kerf along the bottom of the working face across its full length

- Drilling a pattern of blast holes into the working face

- Blasting the coal with chemical agents or charges of compressed gas

- Loading and hauling the fractured coal from the face to a centralized crushing and loadout facility for shipment to the cleaning plant

- Roof bolting with rods, trusses, props, and bolts to ensure the safety of underground personnel and to

Table 5. Estimated productivities of conventional and continuous mining systems for selected seam heights.

MINING SYSTEM	CONVENTIONAL	CONTINUOUS	CONVENTIONAL	CONTINUOUS	CONVENTIONAL	CONTINUOUS
Seam height (inches)	48	48	60	60	72	72
Tons per shift	512	500	640	600	680	700
Total face crew	10	6	10	6	10	6
Work minutes per shift	400	400	400	400	400	400
Man minutes per ton	5.86	3.38	4.69	2.86	4.42	2.44
Tons per man shift	51.2	83.3	64.0	100.0	68.0	116.6

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for the Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455p.

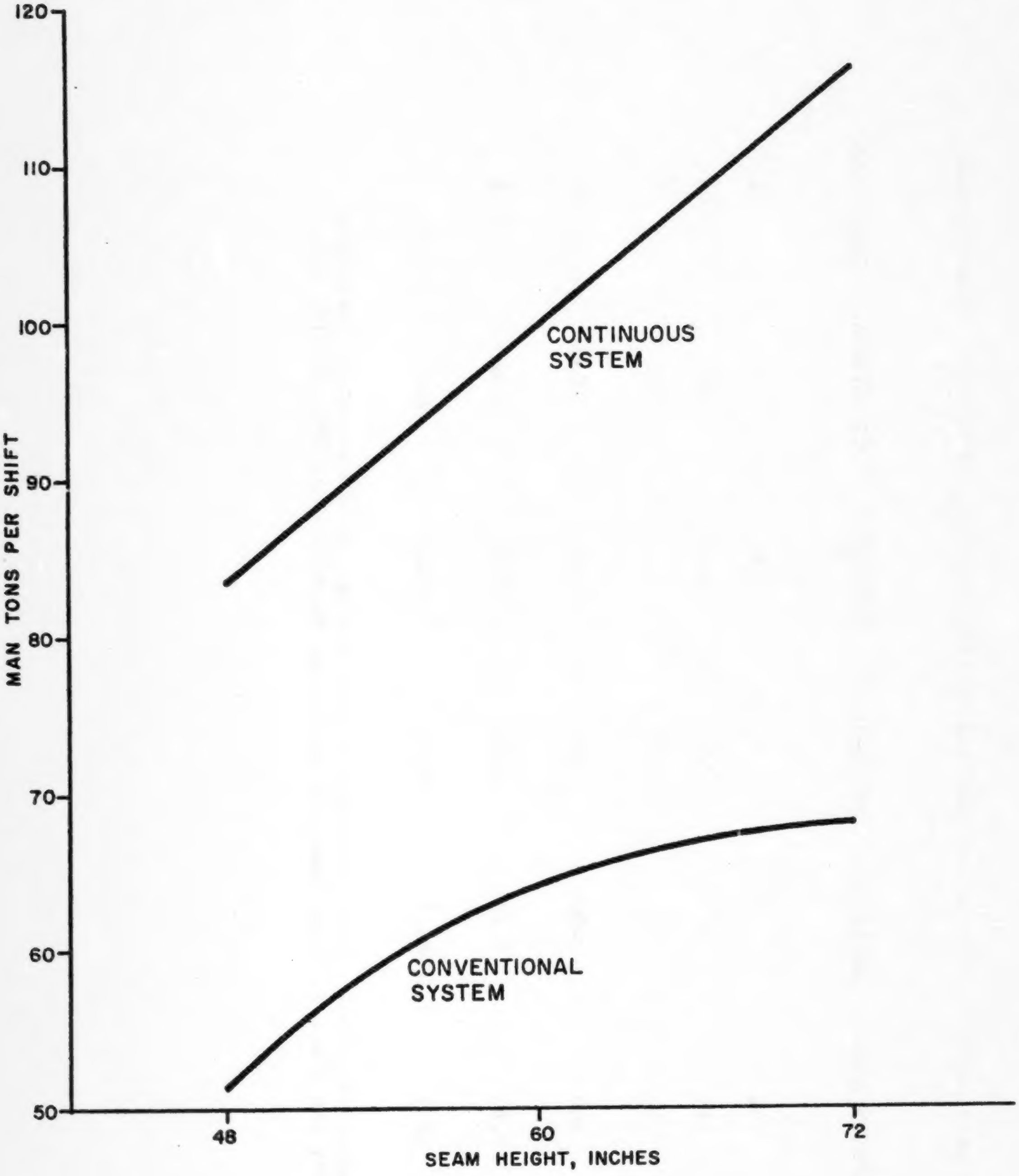


Figure 7. Productivities of conventional and continuous mining systems as functions of seam height, based on data presented in Table 5.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

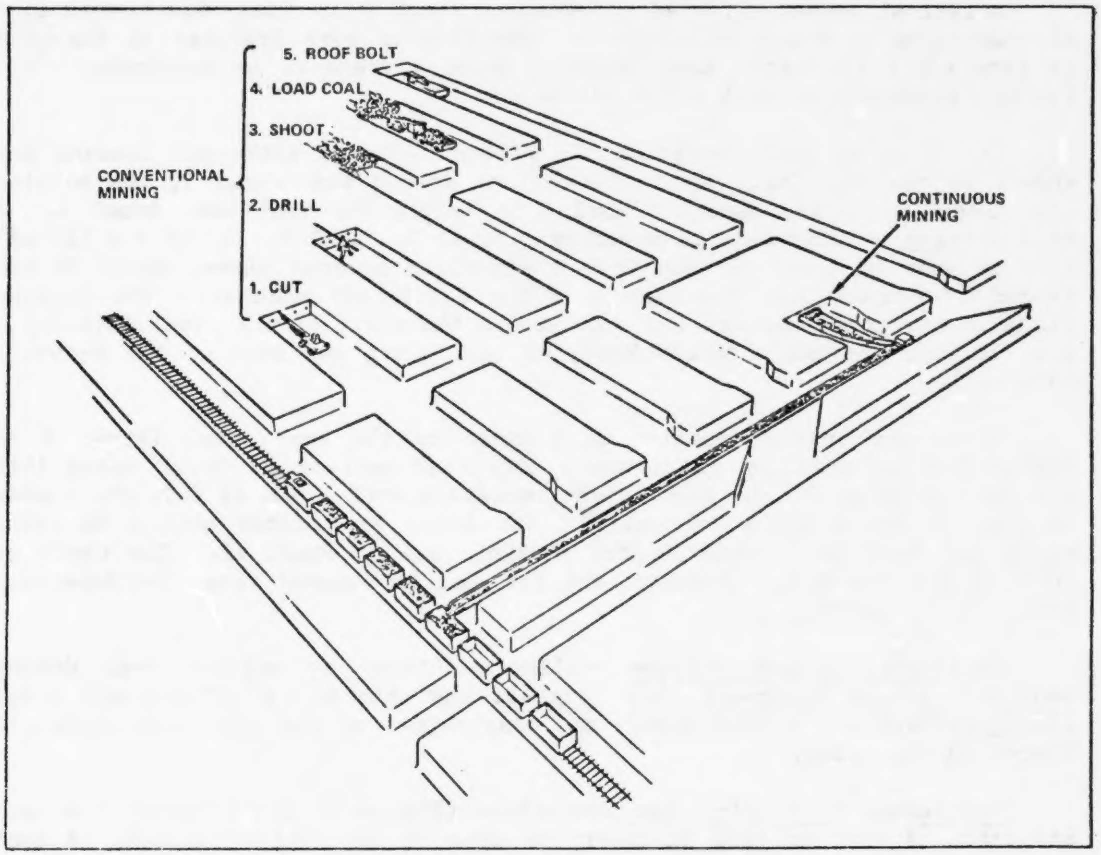

5. ROOF BOLT
4. LOAD COAL
3. SHOOT
CONVENTIONAL MINING
2. DRILL
1. CUT
CONTINUOUS MINING

Figure 8. Room and pillar mining using conventional and continuous techniques.

Source: US Department of Energy. 1978b. International coal technology summary document. Office of Technical Programs Evaluation, HCP/p-3885, Washington DC, 178 p.

minimize the deterioration of roof conditions before a mining section is abandoned.

A typical sequence for mine development and extraction with conventional techniques is shown in Figure 9. The flow of work depicted in Figure 9 is from right to left. Each numbered panel represents an approximate 3 m (10 ft) thickness of coal to be extracted.

The cycle of unit operations in Figure 9 starts with coal loading and ends with roof bolting. After the coal is loaded from Panel 1, the bolting crew moves up to the face of Panel 8 to secure the roof over Panel 1. A coal cutting machine then is moved or trammed to Panel 8. A cut 3 m (10 ft) deep is made in the coal seam with the machine-mounted blade, which is extended or sumped into the seam from the stationary machine. The cutting blade is traversed through the coal across the width of the panel (usually 6 m or 20 ft), leaving a narrow kerf, or slot along the base of the recoverable coal.

After the cutting machine is trammed to the next panel (Panel 9 in Figure 9), the drilling crew cuts a specified pattern of blast holes into the face of Panel 8. As seam height increases over 1.5 m (5 ft), the number of rows of drill holes increases. The holes are loaded with a blasting agent and then shot, exposing the working face of Panel 15. The cycle at Panel 8 then returns to loading, and the coal is removed from the face area ahead of the bolting crew.

Continuous mining systems utilize machinery to extract coal during room-and-pillar, shortwall, and longwall operations. Machinery and panel configurations are chosen within the constraints of the coal seam variables described previously.

Continuous room-and-pillar operations (Figure 8) are based on the capabilities of coal cutting machinery to combine the unit operations of conventional mining techniques (cut, drill, shoot, and load) into one continuous operation that periodically is halted for methane checks; roof bolting; and the installation of electrical, conveyance, and ventilation services. Coal is cut from the face with rippers, borers, augers, and shearers that direct the cuttings to conveyor belts mounted inboard on the machine assembly. These inboard conveyors feed the coal to the mobile conveyor belts, shuttlecars, or load-haul-dump (LHD) vehicles that transport the coal to the permanent haulage system, which may be another conveyor or a train of mine cars pulled by a locomotive.

The continuous auger miner is one of several kinds of coal cutting machines that are available for underground mining. A typical auger type coal cutting machine is shown in plan view in Figure 10. The machine is anchored to a pivot point at the tailpiece. The augers initially are retracted with the auger bits flush against the face wall.

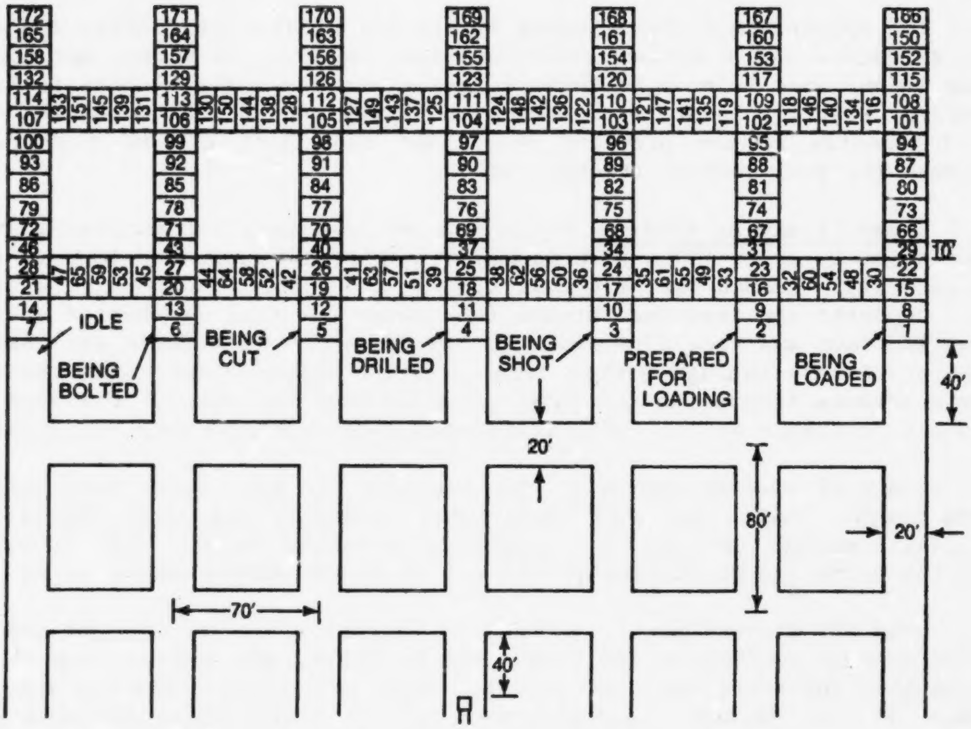

IDLE
BEING BOLTED
BEING CUT
BEING DRILLED
BEING SHOT
PREPARED FOR LOADING
BEING LOADED
10'
40'
20'
80'
20'
70'
40'

Figure 9. Typical sequence of face operations that are used in conventional mining techniques.

Source: Hittman Associates, Inc. 1976. Underground coal mining: as assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

As the cut is made (from left to right in Figure 10), the augers advance into the wall. A chain drive or winch drags the machine sideways against the anchor jack (marked PULL in Figure 10). The direction of pull can be reversed to the anchor jack located to the left of the machine (dead jack) if it is necessary to abort the cut. Coal cuttings are loaded onto the inboard conveyor.

The augers are fully extended by the end of the cut. After the augers are retracted and a methane check is made, the roof is bolted and the pull line anchor jack is brought forward to the new bay. The machine is trammed forward; the tail pivot is anchored, and a new cut is started in the direction opposite to the previous cut. The dead jack of the previous cut becomes the pull jack of the new cut.

Longwall mining systems employ one or more parallel entryways located approximately 90 to 180 m (300 to 600 ft) apart and connected by a cross cut (Figure 11). Mechanical aids that include the cutter, conveyor, shield, and roof supports are inserted through the crosscut. Coal is sheared or planed from the face and then directed onto the conveyor which feeds the coal to a semi-stationary haulage system located in an adjacent entryway. Roof supports advance toward the cut face, thus leaving the roof of the mined area (gob) to collapse as the unsupported overburden subsides into the chamber.

Longwall systems generally are suitable for coal seams that have uniform height, bottom and roof conditions, hardness, and areal distribution. Longwall mining of multiple seams is possible under some conditions. Shallow seams are mined first, followed by progressively deeper seams.

Longwall systems may be impeded by variations in seam height and hardness, undulating bottom and roof, sulfur balls, and channel deposit want areas that interrupt the long cutting passes of automated planers and shearers. Faults, joints, bedding planes, or other structural features in the overburden may prevent the orderly subsidence of mined areas as roof supports are advanced toward the cut face.

Overburden structures and lithologies may cause undesirable shifts in roof loads, contributing to the possible failure of roof support systems. The profile of a desirable caving situation is shown in Figure 12. The overburden pressure (v of Figure 12) increases sharply at a critical distance (4.5 m or 15 ft in Figure 12) behind the face as the pressure arch in the desirable immediate roof transfers the overburden load laterally. The props advance toward the face, and the unsupported roof caves and consolidates, causing the *in situ* pressure of the disturbed overburden to increase above its original value.

The use of longwall systems in coal seams less than 195 m (650 ft) deep may result in a partial collapse of the deeper overburden while shallower strata remain supported by the gob (Figure 13a). Parallel joints in the

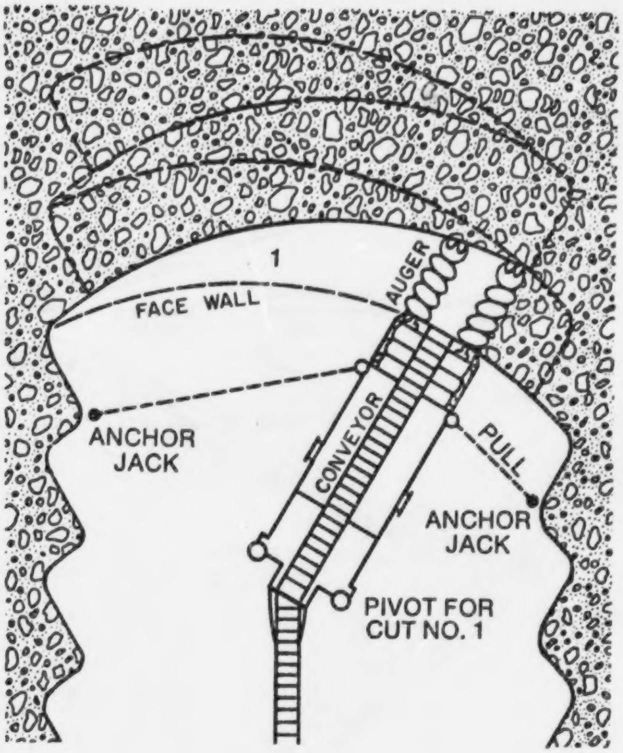

1
FACE WALL
AUGER
CONVEYOR
ANCHOR JACK
PULL
ANCHOR JACK
PIVOT FOR CUT NO. 1

Figure 10. Pivot auger mining machine.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.

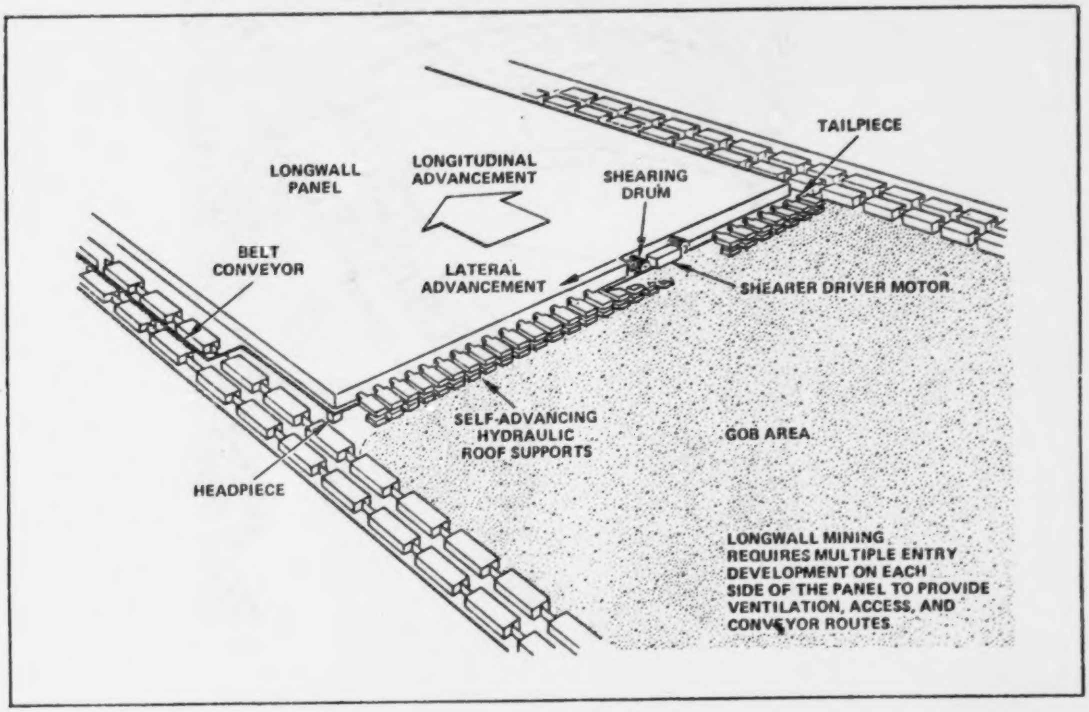

TAILPIECE
LONGWALL PANEL
LONGITUDINAL ADVANCEMENT
SHEARING DRUM
BELT CONVEYOR
LATERAL ADVANCEMENT
SHEARER DRIVER MOTOR
SELF-ADVANCING HYDRAULIC ROOF SUPPORTS
GOB AREA
HEADPIECE
LONGWALL MINING REQUIRES MULTIPLE ENTRY DEVELOPMENT ON EACH SIDE OF THE PANEL TO PROVIDE VENTILATION, ACCESS, AND CONVEYOR ROUTES

Figure 11. Longwall mining system.

Source: US Department of Energy. 1978b. International coal technology summary document. Office of Technical Programs Evaluation, HCP/P-3885, Washington DC, 178 p.

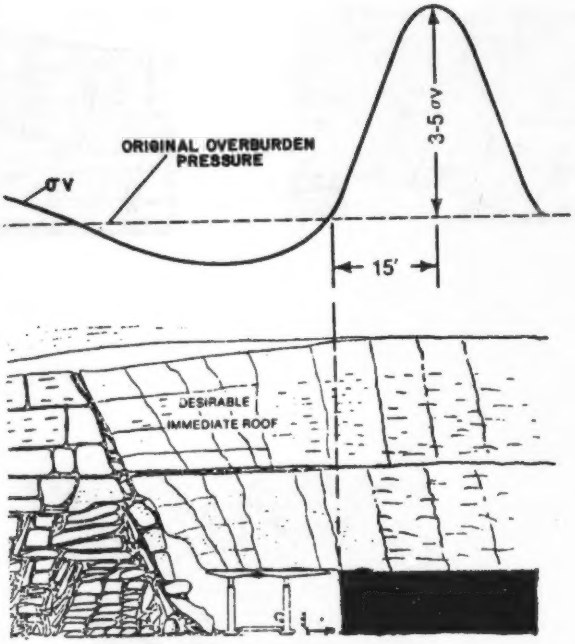
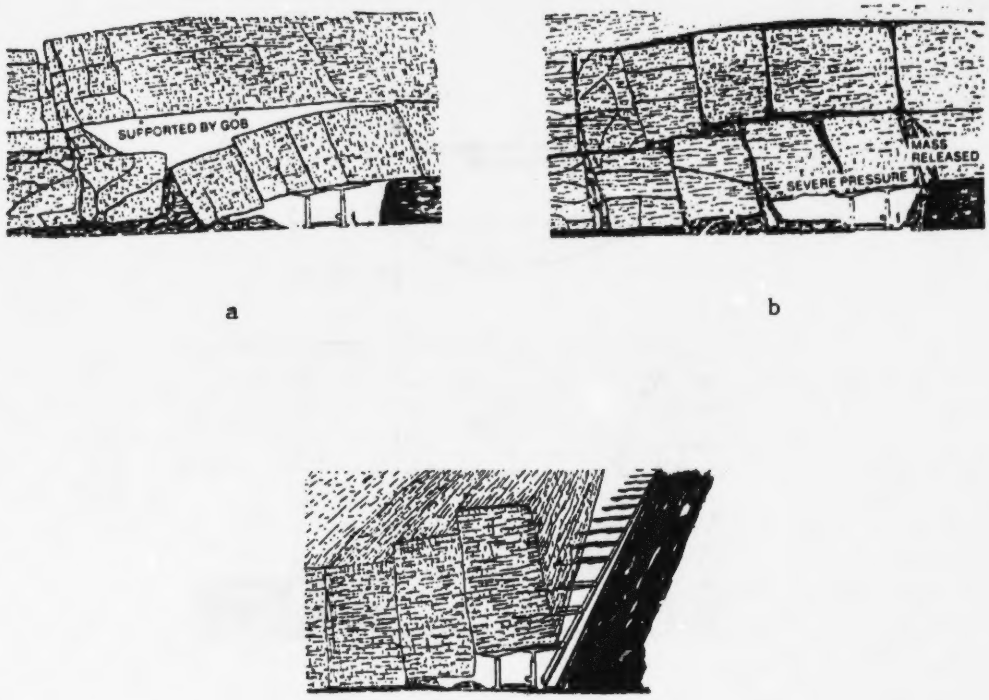

ORIGINAL OVERBURDEN PRESSURE
σV
3-5 σv
15'
DESIRABLE IMMEDIATE ROOF

Figure 12. Ideal caving condition and pressure profile during longwall mining. Dashed line indicates original pressure profile; solid line shows pressure profile during mining.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.


SUPPORTED BY GOB
MASS RELEASED
SEVERE PRESSURE

a

b

c

Figure 13. Natural roof hazards that affect the operation of longwall mining systems. See text for description of hazards.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI AF-219, 455 p.

overlying strata may cause interlocking of large blocks of overburden, producing severe pressures on roof supports and causing the release of loose gob at the face (Figure 13b). Parallel joints at a slight angle to the working face may cause an upset of the roof props (Figure 13c).

Longwall mining systems offer the following advantages over other mining systems (USDOE 1978):

- Lower cost per ton of coal produced
- Higher productivity per man hour
- Higher percentage of recovery of coal resource
- Predictable subsidence
- Adaptability to thick and multiple seams
- Capability to mine at great depths

Shortwall mining systems are similar in principle to longwall systems. During shortwall mining, coal is cut from a panel approximately 45 m (150 ft) long. Roof supports advance toward the panel as mining progresses. The unsupported, undermined areas subside into the void behind the advancing roof supports. The panel length is short enough to be worked economically with the conventional mining machinery used in room-and-pillar systems, although automated shearers also are available for shortwall systems.

Shortwall systems can be used to change existing mining operations from room-and-pillar techniques to wall-type mining techniques without additional costs for the replacement of machinery or revision of plans for mine development. Advanceable roof supports may be the only additional equipment required to consummate the change-over. Shortwall operations also offer the advantage of flexibility in selecting the locations of mining panels or walls to minimize the interruptions in production that result from changes in seam height and the presence of want areas, unsuitable roof and bottom conditions, and gas and oil wells.

1.2.1.2.4. Abandonment

The techniques that are appropriate for the abandonment of an underground mine generally reflect the manner in which the mine was developed. Water infiltrates to the mine void through overlying and adjacent strata. Drift entryways that are advanced up the dip of the coal seam will allow this water to drain freely from the mine, unless suitable seals are installed at the drift mouth (Figure 14). Entryways that are advanced down the dip of the seam must be pumped during mine operation (Figure 15). After abandonment, water drains to the depths of the mine, forming a subterranean pool that may slowly drain to the surface through channels, fractures, and other small voids (Figure 16).

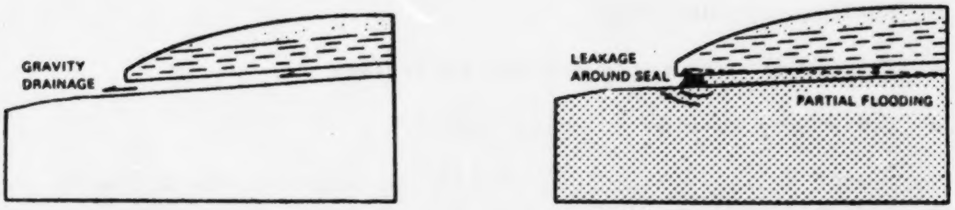

GRAVITY DRAINAGE
LEAKAGE AROUND SEAL
PARTIAL FLOODING

Figure 14. Updip mining from a drift mouth. In (a), the mine drains freely from the drift mouth under force of gravity. In (b), the mine chamber floods against a leaky barrier across the drift mouth.

Source: Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for the US Environmental Protection Agency National Environmental Research Center, Las Vegas NV, 84 p.

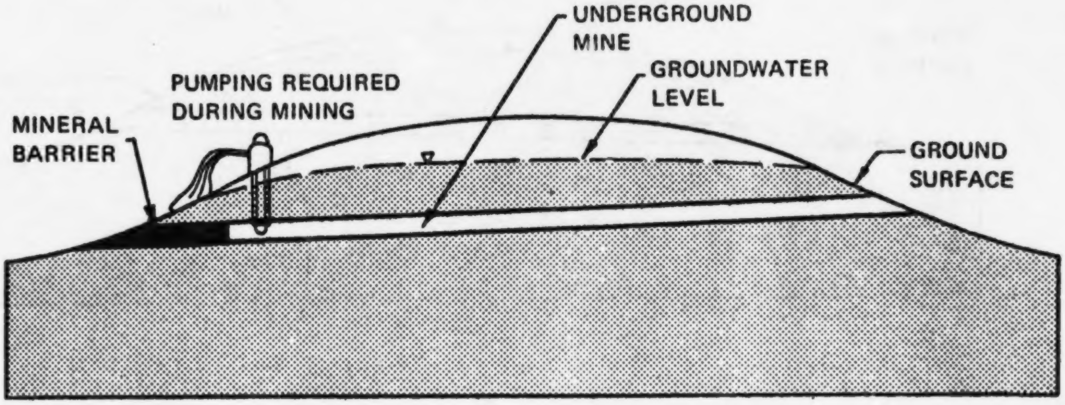

UNDERGROUND MINE
GROUNDWATER LEVEL
PUMPING REQUIRED DURING MINING
MINERAL BARRIER
GROUND SURFACE

Figure 15. Downdip mining from a drift mouth. Mine water is pumped from the depths of the chamber until the workings are abandoned.

Source: Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for the US Environmental Protection Agency National Environmental Research Center, Las Vegas NV, 84 p.

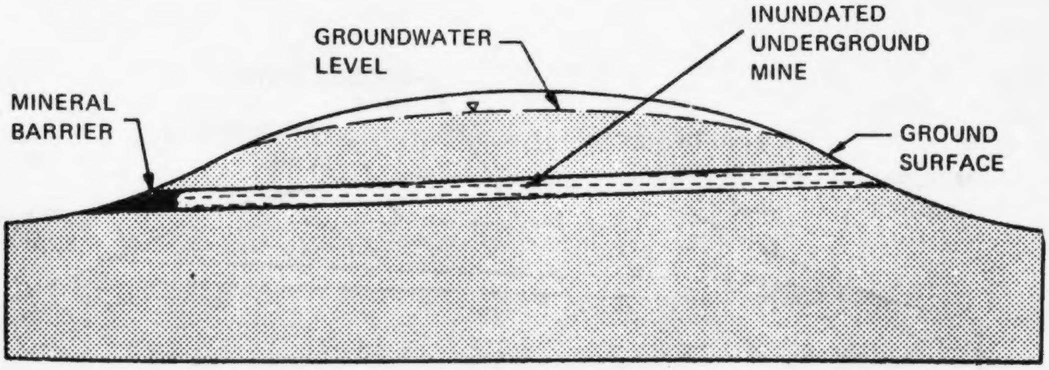

GROUNDWATER LEVEL
INUNDATED UNDERGROUND MINE
MINERAL BARRIER
GROUND SURFACE

Figure 16. Natural flooding of downdip mine after abandonment.

Source: Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for the US Environmental Protection Agency, National Environmental Research Center, Las Vegas NV, 84 p.

The following kinds of seals frequently are installed at mine openings during abandonment:

- Dry seals to prevent the entrance of air and water into mine portals where there is little or no flow of water and minimal potential to develop hydrostatic pressure against the seal
- Air seals to prevent the flow of air into the mine while allowing water to drain from the mine to a treatment facility if required
- Hydraulic seals which plug the discharge from flooded mine voids and exclude air from the mine, thus retarding the oxidation of sulfide minerals.

Hydraulic seals may be employed to seal the drift mouths of entryways that were developed up the dip of the coal seam. A hydraulic seal may include one or more bulkheads (Figures 17 and 18) constructed with timbers, walls of concrete block, backfilled material, and grout curtains injected through boreholes from the surface. These abandonment techniques and others are more thoroughly described in other USEPA publications (USEPA 1973, 1975).

1.2.1.3. Coal Cleaning Operations

The raw coal that leaves the mine site is termed run-of-the-mine (ROM) coal. In most underground mining operations, ROM coal contains oversized material, gob, blasting wire, and the brattice cloth used for routing of face ventilation flow. This coal generally is unsalable without some degree of cleaning or preparation. Coal cleaning facilities range in complexity from relatively simple, off-the-shelf, sizing and crushing machinery to multistage separators and flotation processors which can be designed specifically to clean a few kinds of coal from one or a few neighboring mines for delivery to long-term customers.

The USEPA has an ongoing research and applications program that may significantly affect the future form and economics of current and developing coal cleaning technologies (Section 1.3.3.). Reports of this program describe in detail the coal cleaning technologies currently used by the mining industry (Nunenkamp 1976, McCandless and Shaver 1978). The engineering principles of mechanical coal cleaning also are described more thoroughly in other sources (Leonard and Mitchell 1968, Cummins and Given 1973, Merritt 1978). The following discussion of coal cleaning technology summarizes the elements of mechanical coal preparation in the detail necessary to identify the environmental impacts and pollution control strategies that are discussed in Sections 2.0 and 3.0, respectively.

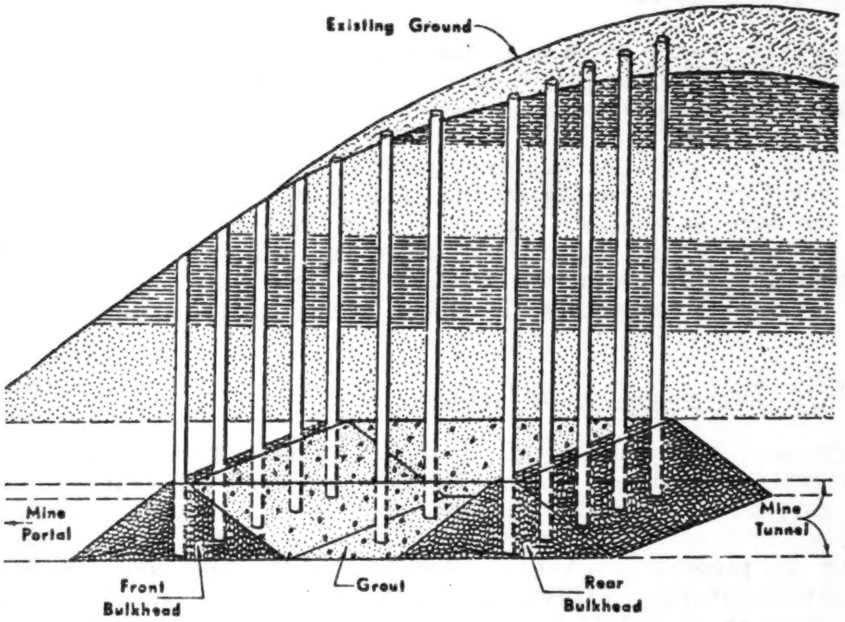

Existing Ground
Mine Portal
Front Bulkhead
Grout
Rear Bulkhead
Mine Tunnel

Figure 17. Cross section of a typical double bulkhead seal.

Source: US Environmental Protection Agency. 1973. Processes, procedures, and methods for controlling pollution from mining activities. EPA 430/9-73-011, Washington DC, 390 p.

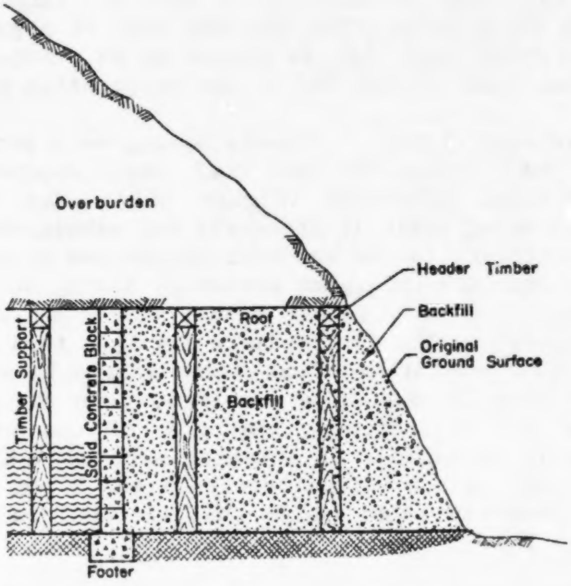

Overburden
Header Timber
Backfill
Original Ground Surface
Roof
Timber Support
Solid Concrete Block
Backfill
Footer

Figure 18. Cross section of a typical single bulkhead seal for drift mouth abandonment.

Source: US Environmental Protection Agency. 1973. Processes, procedures, and methods to control pollution from mining activities. EPA-430/9-73-011, Washington DC, 390 p.

1.2.1.3.1. Process Overview

The mechanical cleaning of coal generally includes the five basic stages (Figure 19) described below. The number of stages employed and the unit operations that comprise each stage may vary among individual operations, although Stages 1, 2, and 3 are common to most of the Nation's coal cleaning facilities (Figure 20).

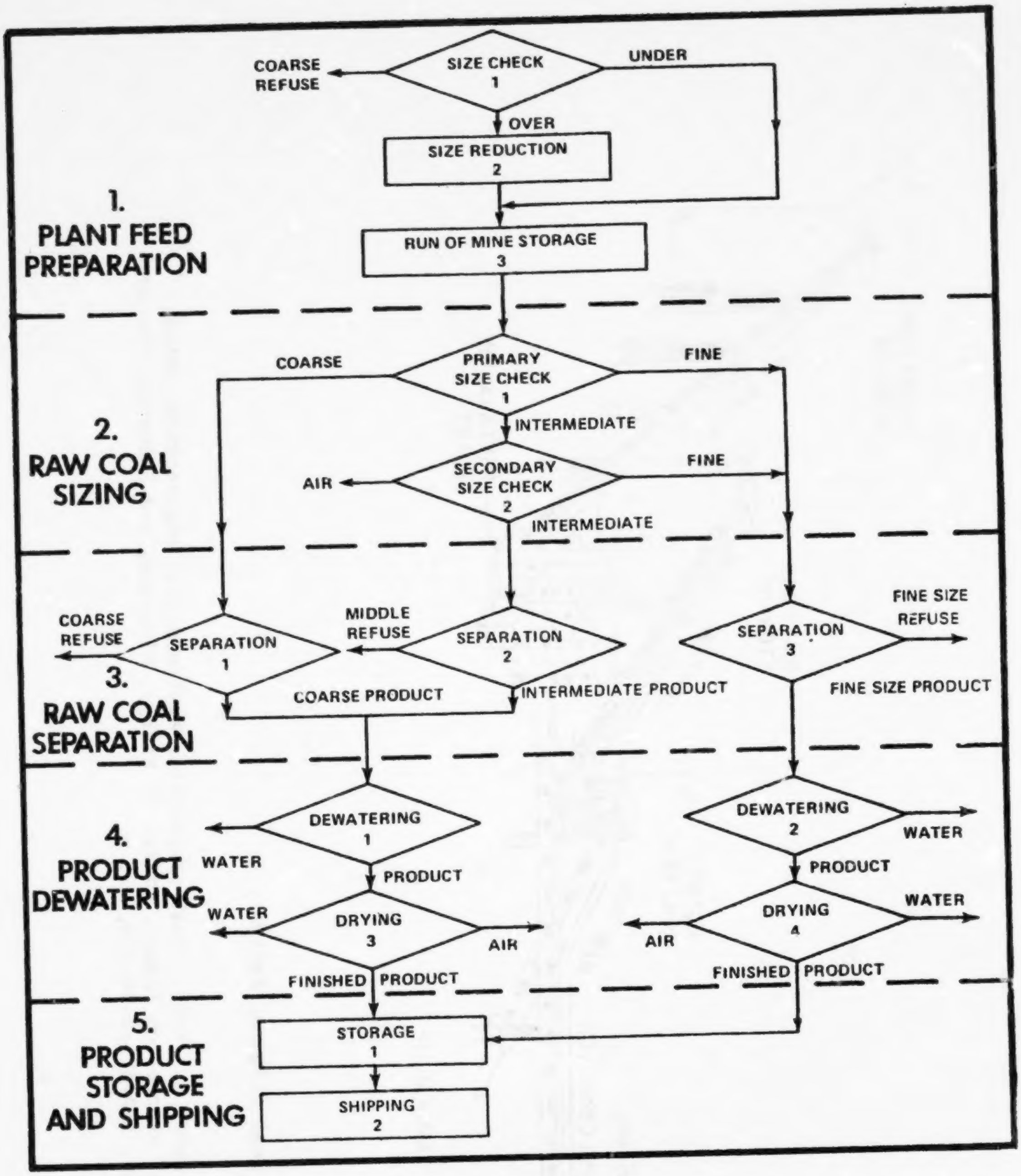
- Stage 1: Plant feed preparation -- Material larger than 21 cm (6 in) is screened from the ROM coal on a grizzly. The properly sized feed coal is ground to an initial size by one or more crushers and fed to the preparation plant.

- Stage 2: Raw coal sizing -- Primary sizing on a screen or a scalping deck separates the coal into coarse- and intermediate-sized fractions (Figure 21). The coarse fraction is crushed again if necessary and subsequently is re-sized for cycling to the raw coal separation step. The intermediate fraction undergoes secondary sizing on wet or dry vibrating screens to remove fines, which may undergo further processing. The intermediate fraction then is fed to the raw coal separator. Coal sizes generally are expressed in inches or mesh size (Table 6). In Figure 21, the notation 4 X 0 indicates that all of the coal is smaller than 10 cm (4 in). A notation such as 4 X 2 indicates that the coal is sized between 5 and 10 cm (2 and 4 in). The notation 4+ indicates that the coal is larger than 10 cm (4 in).

- Stage 3: Raw coal separation -- Approximately 97.5% of the US coal subjected to raw coal separation undergoes wet processes, including dense media separation, hydraulic separation, and froth flotation. Pneumatic separation is applied to the remaining 2.5% (USDOE 1978b). The coarse-, intermediate-, and fine-sized fractions are processed separately by equipment uniquely suited for each size fraction. Refuse (generally shale and sandstone), middlings (carbonaceous material denser than the desired product), and cleaned coal are separated for the dewatering stage.

- Stage 4: Product dewatering and/or drying -- Coarse- and intermediate-sized coal generally are dewatered on screens. Fine coal may be dewatered in centrifuges and thickening ponds and dried in thermal dryers.

- Stage 5: Product storage and shipping -- Size fractions may be stored separately in silos, bins, or open air stockpiles. The method of storage generally depends on the method of loading for transport and the type of carrier chosen.



1. PLANT FEED PREPARATION
COARSE REFUSE
SIZE CHECK 1
UNDER
OVER
SIZE REDUCTION 2
RUN OF MINE STORAGE 3
2. RAW COAL SIZING
COARSE
PRIMARY SIZE CHECK 1
FINE
INTERMEDIATE
AIR
SECONDARY SIZE CHECK 2
FINE
INTERMEDIATE
3. RAW COAL SEPARATION
COARSE REFUSE
SEPARATION 1
MIDDLE REFUSE
SEPARATION 2
SEPARATION 3
FINE SIZE REFUSE
COARSE PRODUCT
INTERMEDIATE PRODUCT
FINE SIZE PRODUCT
4. PRODUCT DEWATERING
DEWATERING 1
WATER
PRODUCT
WATER
DRYING 3
AIR
DEWATERING 2
WATER
PRODUCT
DRYING 4
AIR
WATER
FINISHED PRODUCT
FINISHED PRODUCT
5. PRODUCT STORAGE AND SHIPPING
STORAGE 1
SHIPPING 2

Figure 19. Coal preparation plant processes.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

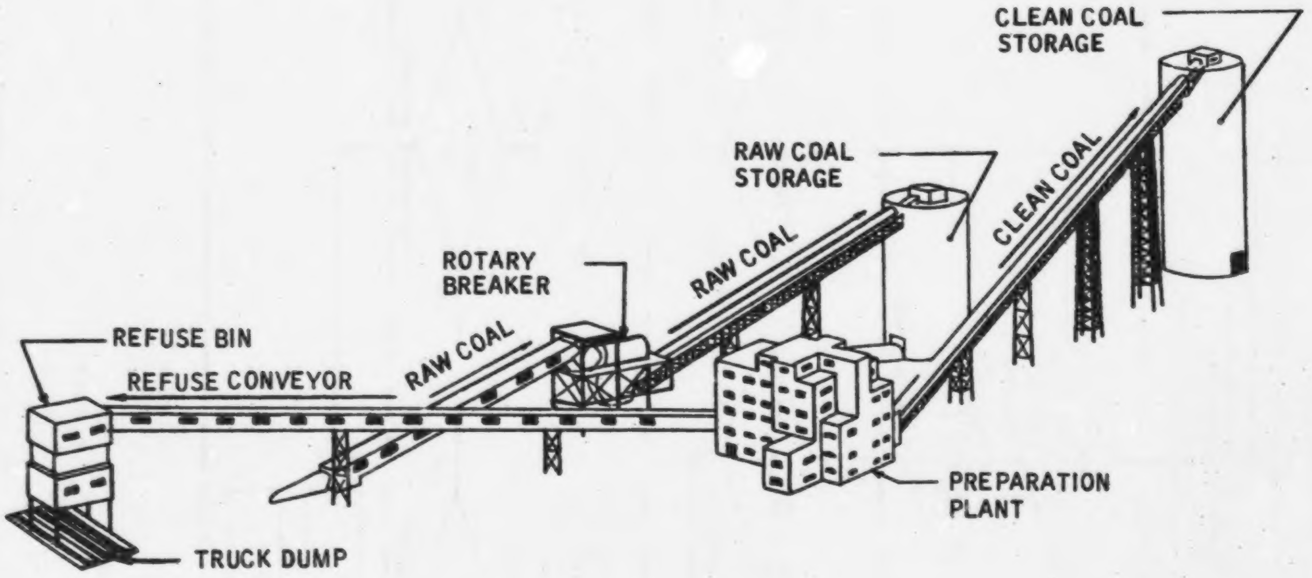

CLEAN COAL STORAGE
RAW COAL STORAGE
CLEAN COAL
ROTARY BREAKER
RAW COAL
REFUSE BIN
REFUSE CONVEYOR
RAW COAL
PREPARATION PLANT
TRUCK DUMP

Figure 20. Typical coal cleaning facility.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

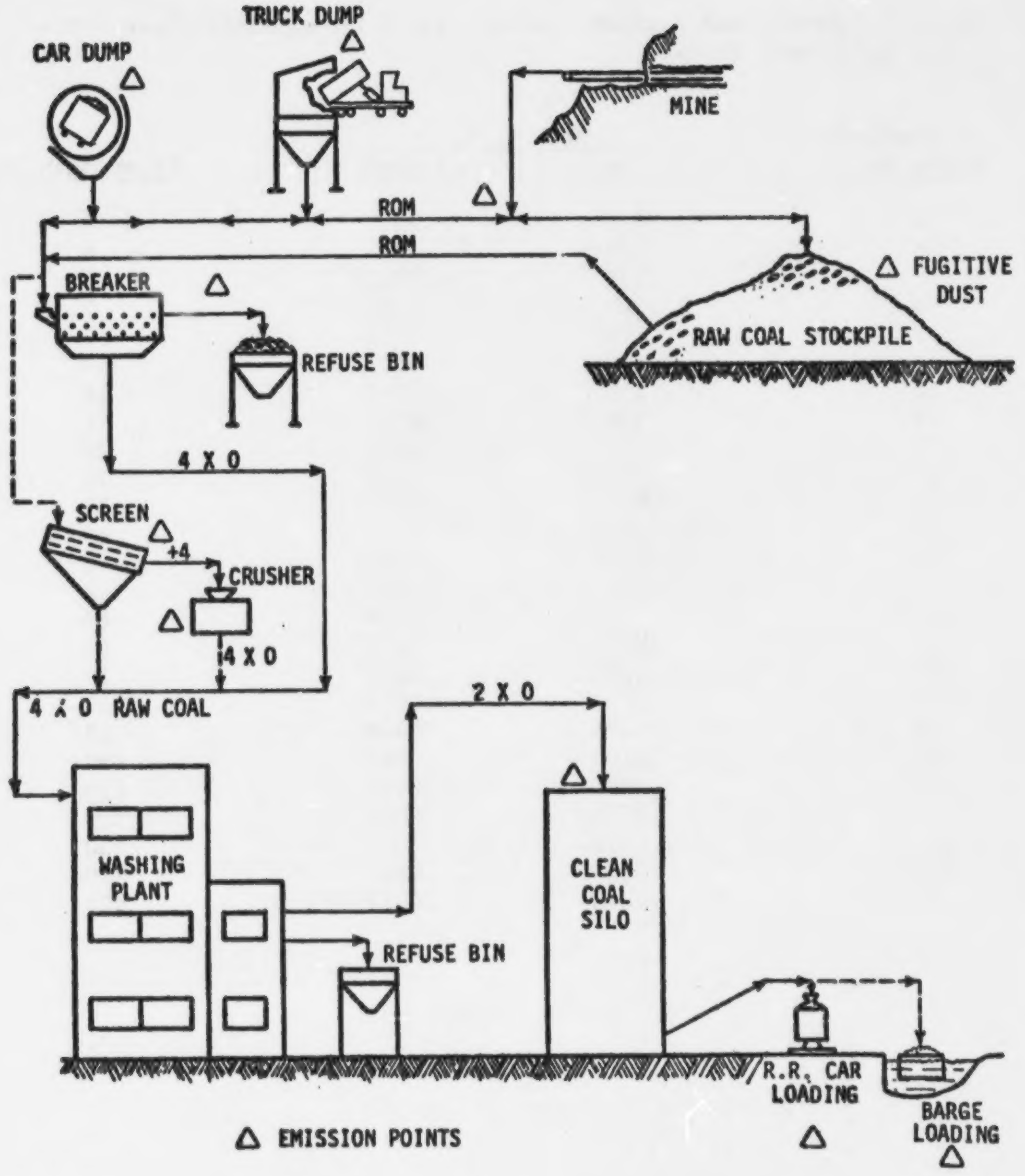

TRUCK DUMP
CAR DUMP
MINE
ROM
ROM
BREAKER
FUGITIVE DUST
RAW COAL STOCKPILE
REFUSE BIN
4 X 0
SCREEN
+4
CRUSHER
4 X 0
4 X 0 RAW COAL
2 X 0
WASHING PLANT
CLEAN COAL SILO
REFUSE BIN
R.R. CAR LOADING
BARGE LOADING
△ EMISSION POINTS

Figure 21. Typical circuit for coal sizing stage.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

Table 6. Metric and English equivalents of US standard sieve sizes and Tyler mesh sizes.

US Standard Sieve No.	Mesh Size		Tyler Mesh No.
	cm	inches	
4	.475	.187	4
6	.335	.132	6
8	.236	.0937	8
10	.20	.0787	9
12	.170	.0661	10
14	.140	.0555	12
16	.118	.0469	14
18	.100	.0394	16
20	.085	.0331	20
30	.06	.0234	28
35	.05	.0197	32
40	.0425	.0165	35
45	.0355	.0139	42
50	.030	.0117	48
60	.025	.0098	60
70	.0212	.0083	65
80	.0180	.0070	80
100	.015	.0059	100
120	.0125	.0049	115
140	.0106	.0041	150
170	.009	.0035	170
200	.0075	.0029	200
230	.0063	.0025	250
270	.0053	.0021	270
325	.0045	.0017	325

For a typical coal cleaning plant with 910 MT (1,000 T) per hour capacity, approximately 70% of the crushed coal reports to the coarse cleaning circuit. Sizing and recrushing of the coarse coal result in the cycling of 34% of the coarse coal charge to the fine and intermediate cleaning circuits. Approximately 27% of the coarse charge is removed as refuse. The remaining 39% is removed as clean product. Process quantities for the fine and intermediate cleaning circuits appear in Table 7.

1.2.1.3.2. Stage Descriptions

The initial screening and crushing of ROM coal at Stage 1 (Figure 19) may be accomplished in one or more substages (Figure 22). The grizzly can be a set of iron bars, welded on 21 cm (6 in) centers to a rectangular frame. Oversized material that would otherwise inhibit the operation of the primary crusher is scalped from the feed coal on the grizzly bars. In a multicrusher system, the output from the primary crusher is screened. Oversized coal is fed to the next in a series of crushers, and finer material reports directly to sizing and separation stages.

The types of mills that are available for Stage 1 crushing include rotary breakers, single and double roll crushers, hammermills, and ring crushers. Each type of mill is available in various models which crush the ROM coal at different rates to different sizes. The general characteristics of crushing mills appear below (McLung 1968).

- Rotary breaker - Often called the Bradford breaker after its inventor, this large, rotating cylinder is driven at 12 to 18 revolutions per minute by an electric motor via a chain and reducer drive. ROM coal is introduced through one end of the cylinder and is crushed against the encircling steel plates. The crushed coal exits the breaker through the precut holes in the plates and feeds to a conveyor. Slate, overburden, rock, and other gangue materials that resist breakage are carried by a series of baffles to the far end of the cylinder, where they are removed from the mill by a continuously rotating plow.

- Single- and Double-Roll Crushers - A roll crusher comprises one or two steel rollers studded with two different lengths of heavy teeth. The long teeth slice the large pieces of coal into fragments and feed the flow of coal into the smaller teeth, which make the proper size reduction. In single-roll mills, the coal is crushed against a stationary breaker plate (Figure 23a). Double-roll crushers also fragment the coal with specially designed teeth. Crushing action against the rollers (between the teeth) is minimal (Figure 23b). Both mills are fed through the top. Product exits through the bottom.

Table 7. Typical process quantities for a 910 MT (1,000 T) per hour coal cleaning facility.

	Washing circuit		Dewatering circuit		Process water		Refuse recovery	
	MT/hr	%	MT/hr	%	1/m	%	MT/hr	%
Coarse coal fraction	630	69	245	39	3,293	12	173	63
Intermediate coal fraction	190	21	330	52	7,040	26	82	30
Fine coal fraction	90	10	58	9	16,427	61	19	6
Thermal dryer dust							3	1
Total	910	100	633	100	26,760	100	277	100

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Research and Development, EPA-600/2-76-138, Washington DC, 727 p.

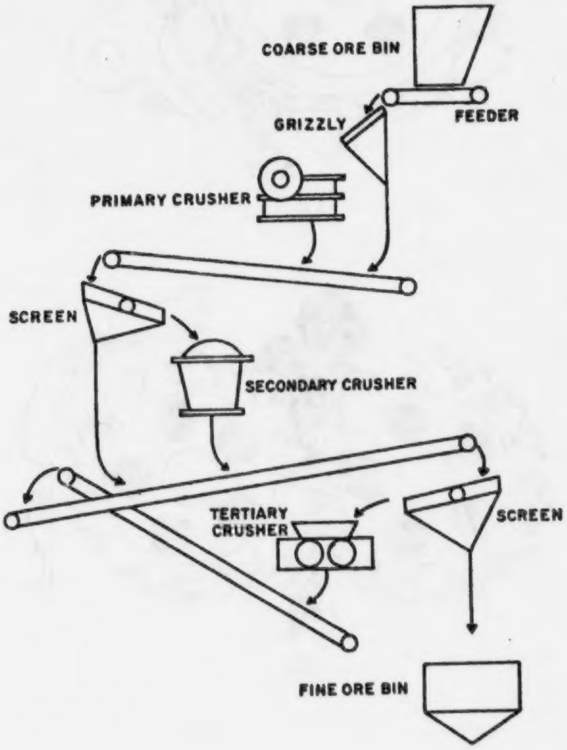

COARSE ORE BIN
FEEDER
GRIZZLY
PRIMARY CRUSHER
SCREEN
SECONDARY CRUSHER
TERTIARY CRUSHER
SCREEN
FINE ORE BIN

Figure 22. Typical three stage crusher system for raw coal crushing.

Source: Cummins, A. B. and I. A. Given (Editors). 1973. SME mining engineering handbook. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, variously paged.

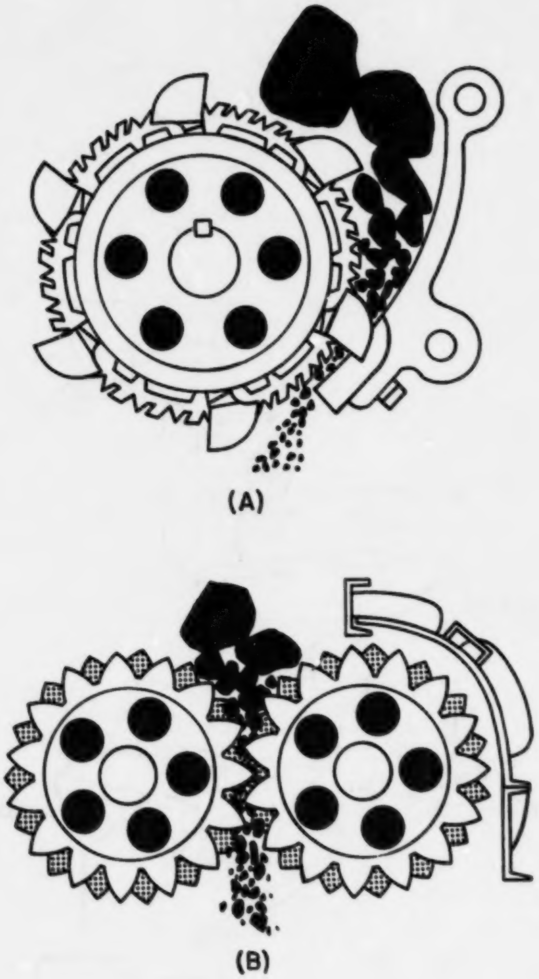


Figure 23. Single-roll (a) and double-roll (b) crushers for sizing of raw coal.

Source: McClung, J. D. 1968. Breaking and crushing. In Joseph W. Leonard and David R. Mitchell (eds.). 1968. Coal preparation. 3rd edition. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, 926 p.

- Hammermill - This mill uses a set of hammers to strike the feed coal against a breaker base plate. The rebounding fragments are swept against a perforated steel plate or crushing grate and discharged to a bin or conveyor.

- Ring crusher - The principles of hammermill and ring crusher operations are similar. Instead of hammers, the ring crusher uses a set of smooth and toothed rings to drive the feed coal against the breaker plate.

The unit operations that commonly are employed at Stages 2 and 3 of Figure 19 (sizing and separation, respectively) vary considerably among modern cleaning installations nationwide. The choice of unit operations for a particular installation depends on a number of factors, including coal preparation objectives, availability and costs of equipment, and operator experience. Nine of the typical unit operations that currently are employed during the sizing and separation steps are listed below (McCandless and Shaver 1978). Water requirements, sizes and rates of feed, and dewatering efficiencies of selected unit processes are described in Table 8.

- Dense media - Light, cleaned coal is continuously skimmed from a slurry of raw coal and controlled-density fluid (usually magnetite; Figure 24). Accuracy of separation is sharp from 0.059 to 20 cm (0.02 to 8 in). Quality and sizes of feed can fluctuate widely.

- Froth flotation - A slurry of coal and collector agents is blended to induce water-attracting tendencies in selected fractions of the feed coal. After the addition of a frothing agent, finely disseminated air bubbles are passed through the slurry. Selected coal particles adhere to the air bubbles and float to the surface, to be skimmed off the top. The process can separate fractions in a band of 0.045 to 1.18 mm (0.002 to 0.05 in).

- Humphrey spiral - A slurry of coal and water is fed into the top of a spiral conduit. The flowing particles are stratified by differences in density, with the denser fractions flowing closer to the wall of the conduit. A splitter at the end of the stream separates the stratified slurry into final product and middlings. These products are fed to separate dewatering facilities.

- Hydrocyclones - A slurry of coal and water is subjected to centrifugal forces in an ascending vortex. The denser refuse material forms a layer at the bottom of the vessel. Circulating water skims the clean coal from the top of the stratified slurry and directs the product to a vortex

Table 8. Feed characteristics of unit cleaning operations for sizing and separation of crushed coal.

COAL CLEANING UNIT	WATER REQUIRED PER MT OF FEED (lph)	MAXIMUM FEED RATE (MTph)	RANGE OF[1] FEED SIZES (cm)	% SOLIDS IN FEED
Baum jig	12 to 21	9.8 to 48 per m^2 of jig area	0.3 to 20	85 to 90
Belknap washer	21	145	0.6 to 15	85 to 90
Chance cone	29 to 50	488 per m^2 of cone area	0.2 to 20	85 to 90
Concentrating table	50 to 67	9.1 to 14	0 to 0.6	20 to 35
DSM heavy media cyclone	83 to 125 (heavy media slurry)	4.5 to 32	0 to 0.6	12 to 16
Flotation cell	54 to 67	1.8 to 3.6	0.030 to 0.0075	20 to 30
Humphrey spiral	125	0.9 to 1.4	0.6 to 0.0075	15 to 20
Hydroseparator	58 to 75	1.4 per vertical cm of vessel	1.3 to 13	85 to 90
Hydrotator	50 to 67	49 per m^2 of surface	0 to 5.1	85 to 90
Menzies cone	58 to 75	273	1.3 to 13	85 to 90

Table 8. Feed characteristics of unit cleaning operations for sizing and separation of crushed coal (concluded).

COAL CLEANING UNIT	WATER REQUIRED PER MT OF FEED (lph)	MAXIMUM FEED RATE (tph)	RANGE OF[1] FEED SIZES (cm)	% SOLIDS IN FEED
Rheolaveur free discharge	12 to 17	1.1 to 1.8 per cm of vessel	0 to 0.6	15 to 30
Rheolaveur sealed discharge	25 to 50	2.9 to 3.6 per cm of vessel	0.6 to 10	15 to 30

[1] Range of feed sizes is listed for bituminous coal only. Anthracite feeds for Menzies cones and hydroseparators range between 0.08 and 13 cm. The DSM cyclone accepts anthracite feeds between 48 mesh and 0.75 in. The flotation cell accepts 200 to 28 mesh. The Belknap washer does not process anthracite.

Source: Aplan, F. F. and R. Hogg. 1979. Characterization of solid constituents in blackwater effluents from coal preparation plants. Prepared for the US Environmental Protection Agency and US Department of Energy, EPA-600/7-79-006, FE-9002-1, Washington DC, 203 p.

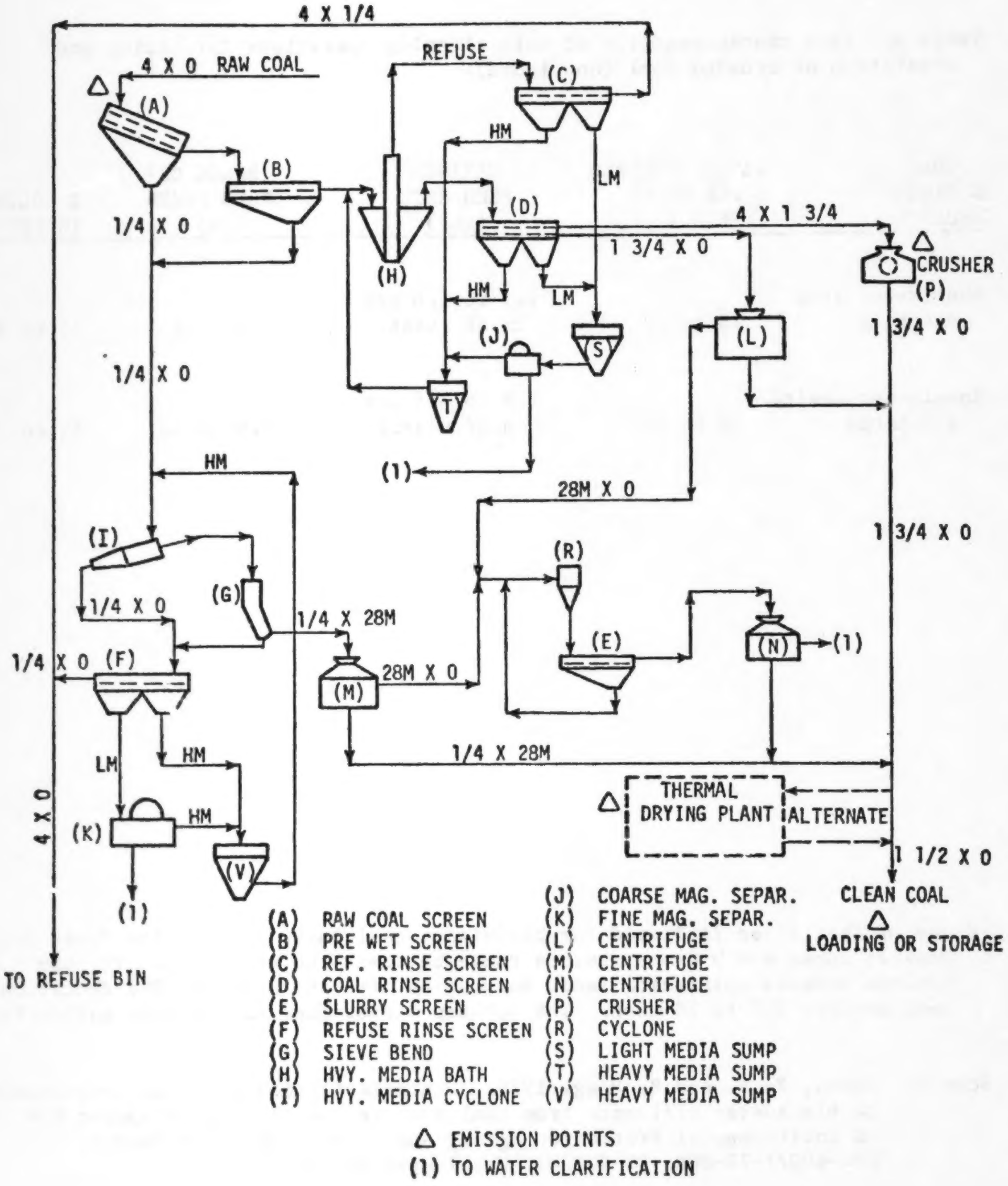

4 X 1/4
4 X 0 RAW COAL
REFUSE
(A)
(B)
(C)
(D)
(H)
HM
LM
1/4 X 0
4 X 1 3/4
1 3/4 X 0
CRUSHER
(P)
1 3/4 X 0
HM
LM
(J)
(S)
(L)
(T)
1/4 X 0
HM
(1)
28M X 0
1 3/4 X 0
(I)
(R)
(G)
1/4 X 0
1/4 X 28M
(E)
(N)
(1)
1/4 X 0
(F)
(M)
28M X 0
LM
HM
1/4 X 28M
4 X 0
THERMAL DRYING PLANT
ALTERNATE
(K)
HM
1 1/2 X 0
(V)
(1)
CLEAN COAL
LOADING OR STORAGE
TO REFUSE BIN
(A) RAW COAL SCREEN
(B) PRE WET SCREEN
(C) REF. RINSE SCREEN
(D) COAL RINSE SCREEN
(E) SLURRY SCREEN
(F) REFUSE RINSE SCREEN
(G) SIEVE BEND
(H) HVY. MEDIA BATH
(I) HVY. MEDIA CYCLONE
(J) COARSE MAG. SEPAR.
(K) FINE MAG. SEPAR.
(L) CENTRIFUGE
(M) CENTRIFUGE
(N) CENTRIFUGE
(P) CRUSHER
(R) CYCLONE
(S) LIGHT MEDIA SUMP
(T) HEAVY MEDIA SUMP
(V) HEAVY MEDIA SUMP
△ EMISSION POINTS
(1) TO WATER CLARIFICATION

Figure 24. Typical circuit for dense media coal cleaning.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, EPA-340/1-77-022, 156 p.

finder, which feeds the cyclone overflow into the product dewatering stage (Nunenkamp 1976). Feed coal sizes range between 0.044 and 64 mm (0.002 and 2.5 in).

- Jigging - A slurry of coal and water is stratified by pulsating fluid. Clean, low density coal is skimmed from the top of the vessel. The accuracy of separation is low. Sizes of feed coal range between 3.4 and 76 mm (0.1 and 3 in; Figure 25).
- Launders - Raw coal is fed with a stream of water into the high end of a trough. The coal-water stream stratifies as it flows down the incline. The denser refuse material forms the bed load of the trough while the less dense coal is suspended in the stream. The cleaned product is split from the stream at the low end of the trough. Feed coal sizes range between 4.76 and 76 mm (0.19 and 3 in).
- Pneumatic - Streams of pulsating air stratify the feed coal across a table equipped with alternating decks and wells (Figure 26). Refuse is pushed into the wells and withdrawn under the table. The cleaned product rides over the refuse and is withdrawn at the discharge end of the table. Feed coal sizes range to a maximum of 9.5 mm (0.38 in; Figure 27).
- Two stage flotation - The first stage proceeds as previously described for froth flotation. During the second stage, the frothed coal is re-slurried with water and treated with an organic colloid to prevent the coal from refrothing. A xanthate collecting agent and an alchohol frothing agent are added to the slurry, causing the pyritic gangue to float to the top of the vessel, whence it is skimmed and concentrated. Pyritic sulfur content of the feed coal is reduced up to 90%. Approximately 80% of the coal's original heating value is recovered.
- Wet tables - A slurry of coal and water is floated over a table that pulsates with a reciprocating motion. Denser refuse materials flow toward the sides of the table, while the cleaned coal is skimmed from the center. Feed coal sizes range between 0.15 and 6.4 mm (100 mesh and 0.25 in).

The process waters used during the coal separation stage generally are maintained between pH 6.0 and 7.5. Waters with lower pH inhibit the flotation of both coal and ash-forming substances. As pH increases, the percentage of floating coal maximizes, but the percentage of floating refuse also increases. The pH of process waters may be elevated with lime. Reagents may be added to control the percentage of suspended fines (Zimmerman 1968).

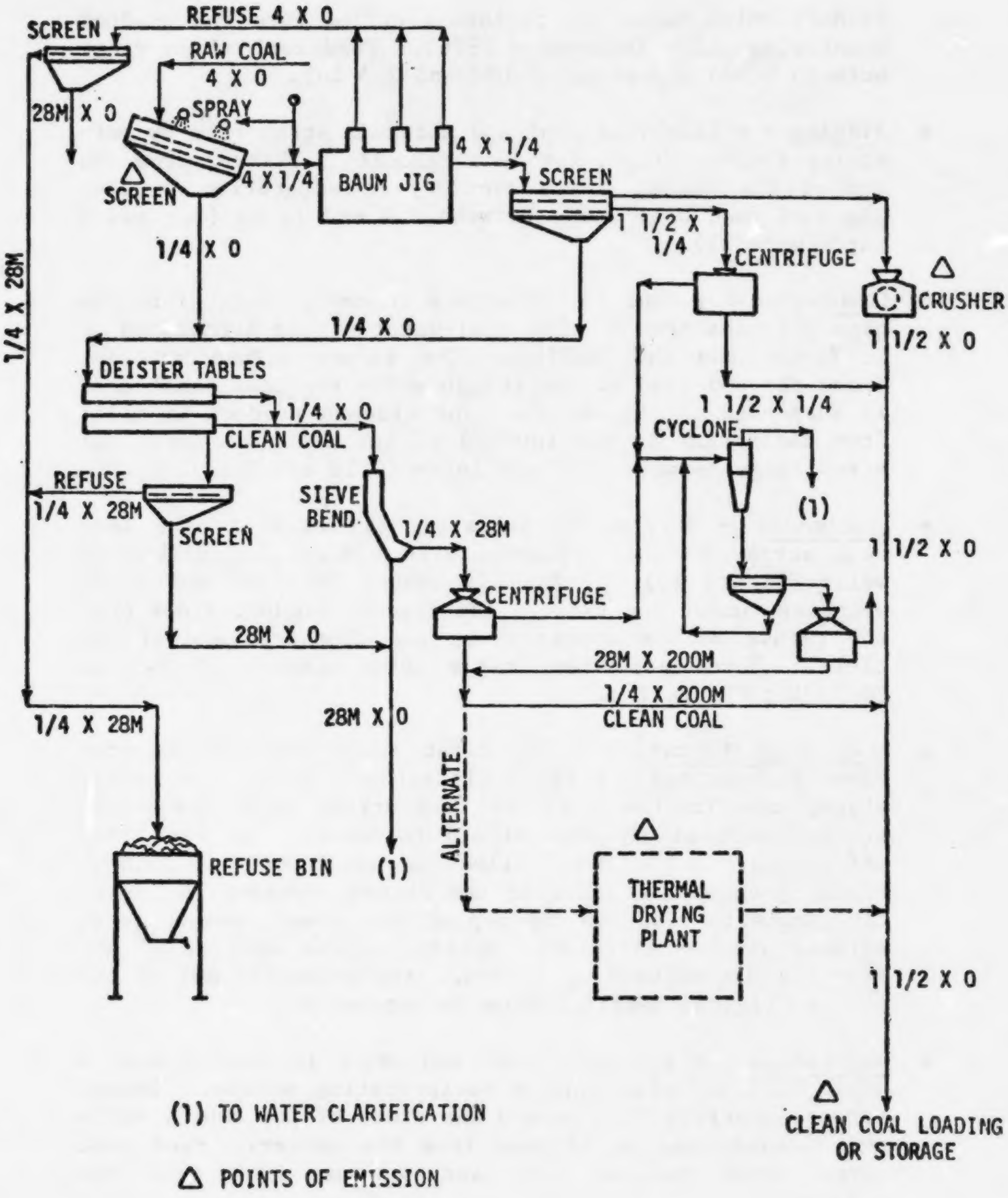

SCREEN
REFUSE 4 X 0
RAW COAL
4 X 0
28M X 0
SPRAY
SCREEN
4 X 1/4
BAUM JIG
4 X 1/4
SCREEN
1 1/2 X 1/4
CENTRIFUGE
CRUSHER
1/4 X 0
1/4 X 28M
1/4 X 0
1 1/2 X 0
DEISTER TABLES
1/4 X 0
CLEAN COAL
1 1/2 X 1/4
CYCLONE
(1)
REFUSE
1/4 X 28M
SCREEN
SIEVE BEND
1/4 X 28M
1 1/2 X 0
CENTRIFUGE
28M X 0
28M X 200M
1/4 X 200M
CLEAN COAL
1/4 X 28M
28M X 0
ALTERNATE
REFUSE BIN
(1)
THERMAL DRYING PLANT
1 1/2 X 0
(1) TO WATER CLARIFICATION
△ POINTS OF EMISSION
CLEAN COAL LOADING OR STORAGE

Figure 25. Typical circuit for jig table coal cleaning.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

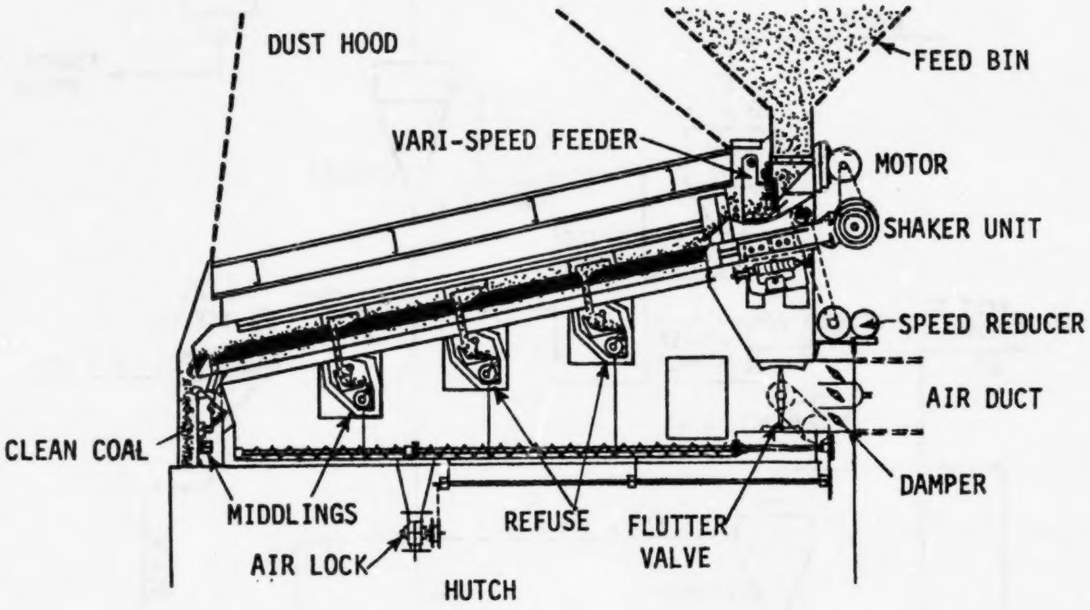
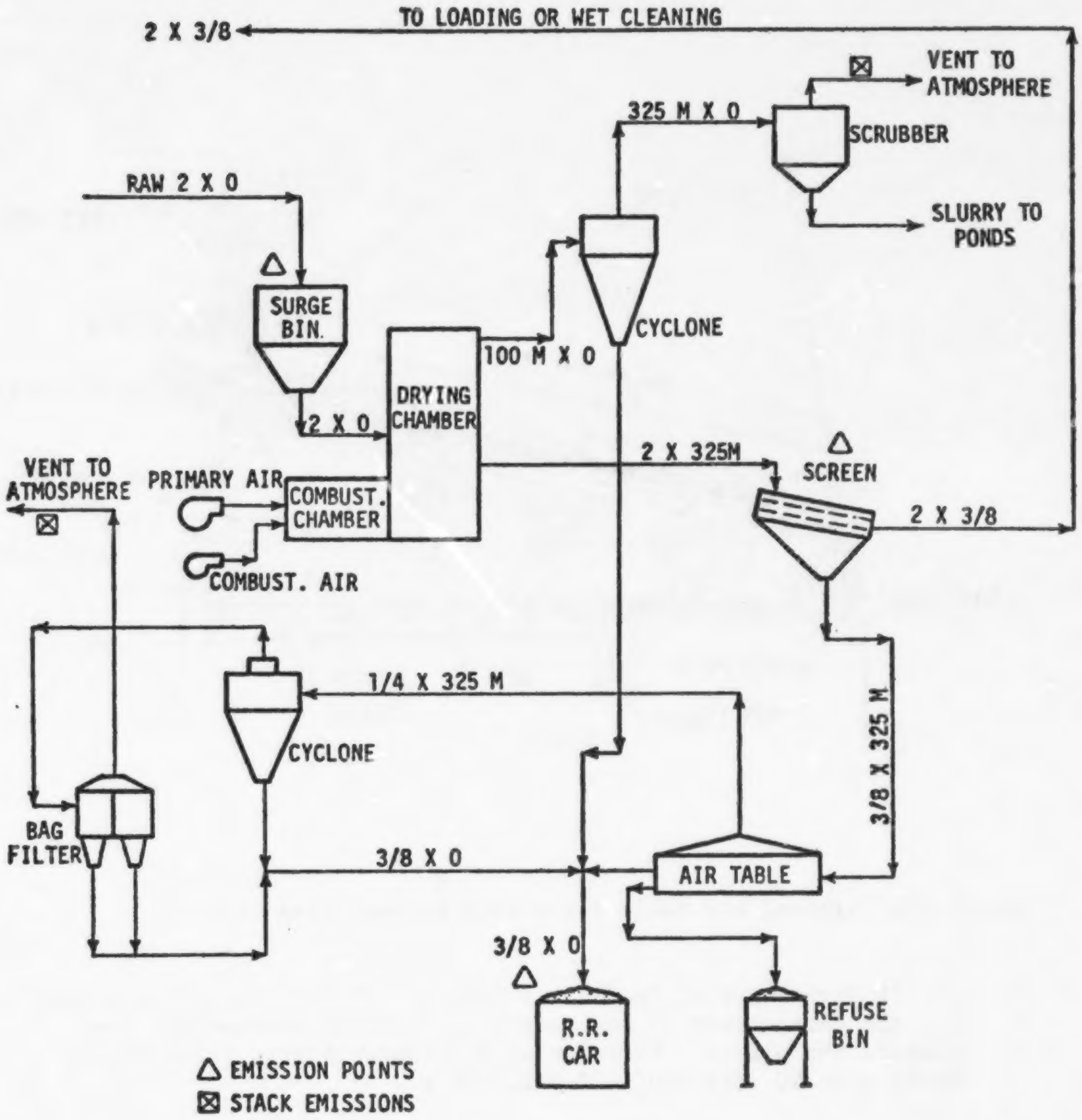

DUST HOOD
FEED BIN
VARI-SPEED FEEDER
MOTOR
SHAKER UNIT
SPEED REDUCER
AIR DUCT
CLEAN COAL
DAMPER
MIDDLINGS
REFUSE
FLUTTER VALVE
AIR LOCK
HUTCH

Figure 26. Typical air table for pneumatic coal cleaning.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.



2 X 3/8
TO LOADING OR WET CLEANING
VENT TO ATMOSPHERE
325 M X 0
SCRUBBER
SLURRY TO PONDS
RAW 2 X 0
SURGE BIN
CYCLONE
100 M X 0
DRYING CHAMBER
2 X 0
2 X 325M
SCREEN
2 X 3/8
VENT TO ATMOSPHERE
PRIMARY AIR
COMBUST. CHAMBER
COMBUST. AIR
1/4 X 325 M
CYCLONE
3/8 X 325 M
BAG FILTER
3/8 X 0
AIR TABLE
3/8 X 0
R.R. CAR
REFUSE BIN
△ EMISSION POINTS
☒ STACK EMISSIONS

Figure 27. Typical circuit for pneumatic coal cleaning.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

Make-up water for cleaning plant operation ideally has a neutral pH, low conductivity, and low bicarbonate content. The water preferably is free from contamination by sewage, organic material, and acid mine drainage. Other dissolved constituents also should occur in low concentrations (Table 9).

Product dewatering (Stage 4 of Figure 19) includes the use of mechanical devices, thermal dryers, and agglomeration processes to reduce the moisture contents of processed coal and refuse (McCandless and Shaver 1978; Figure 28). The moisture contents of products dried by typical processes appear in Table 10. Mechanical processes are of two general types:

- In-stream processes that do not produce a final product (hydrocyclones and static thickeners). These processes remove approximately 30 to 60% of the moisture in feed material. Thickeners and cyclones usually are placed on line with other drying devices that reduce the moisture contents further.

- End-of-stream processes that produce a final product (screens, centrifuges, spiral classifiers, and filters).

Several of the processes that are used for Stage 3 separation also are used for Stage 4 dewatering, including hydrocyclones, centrifuges, and spiral classifiers. These processes are described above. Static thickeners, screens, and filters may also have a separation function, but are more appropriately described as dewatering processes.

- Static thickeners generally are used in conjunction with flocculants to settle the fines from a static pool of preparation plant refuse water (blackwater). A typical thickener feed contains 1 to 5% solids; thickened underflow contains 20 to 35% solids. Common flocculants include inorganic electrolytes such as lime and alum, and organic polymers such as starches and polyacrylamide (Aplan and Hogg 1977). Sludge from the thickener underflow may be dewatered further by mechanical devices, thermal drying, or agglomeration. A typical thickener vessel appears in Figure 29.

- Screens serve dual functions of dewatering and sizing. The mode of operation (fixed or vibrating), mesh size, and bed depth of feed material are chosen on the basis of raw feed characteristics (gradation and moisture content), feed rates, and the desired efficiency of sizing and

Table 9. Desirable chemical characteristics of make-up water for coal cleaning processes.

Parameter	Concentration[a] (mg/l)
pH	7.8
Hardness as $CaCO_3$	190
Ca	64
Mg	7.5
Na	19
K	4.7
NH_4	0.4
CO_3	0
HCO_3	157
Cl	35
SO_4	49
NO_3	15
NO_2	Trace
PO_4	0.5
SiO_2	7.2

---

[a] pH expressed in standard units.

Source: Lucas, J. Richard, David R. Maneval, and W. E. Foreman. 1968. Plant waste contaminants. In : Leonard, Joseph W. and David R. Mitchell. 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, 926 p.

Table 10. Typical moisture contents of dried product from selected drying operations in coal cleaning facilities.

Type of Equipment or Process	Moisture Content of Discharge Product (%)
Dewatering screens	8 to 20
Centrifuges	10 to 20
Filters	20 to 50
Hydraulic cyclones	40 to 60
Static thickeners	60 to 70
Thermal dryers	6 to 7.5
Oil agglomeration	8 to 12

Source: McCandless, Lee C., and Robert B. Shaver. 1978. Assessment of coal cleaning technology: first annual report. US Environmental Protection Agency, Office of Research and Development, Washington DC, EPA-600/7-78-150, 153 p.

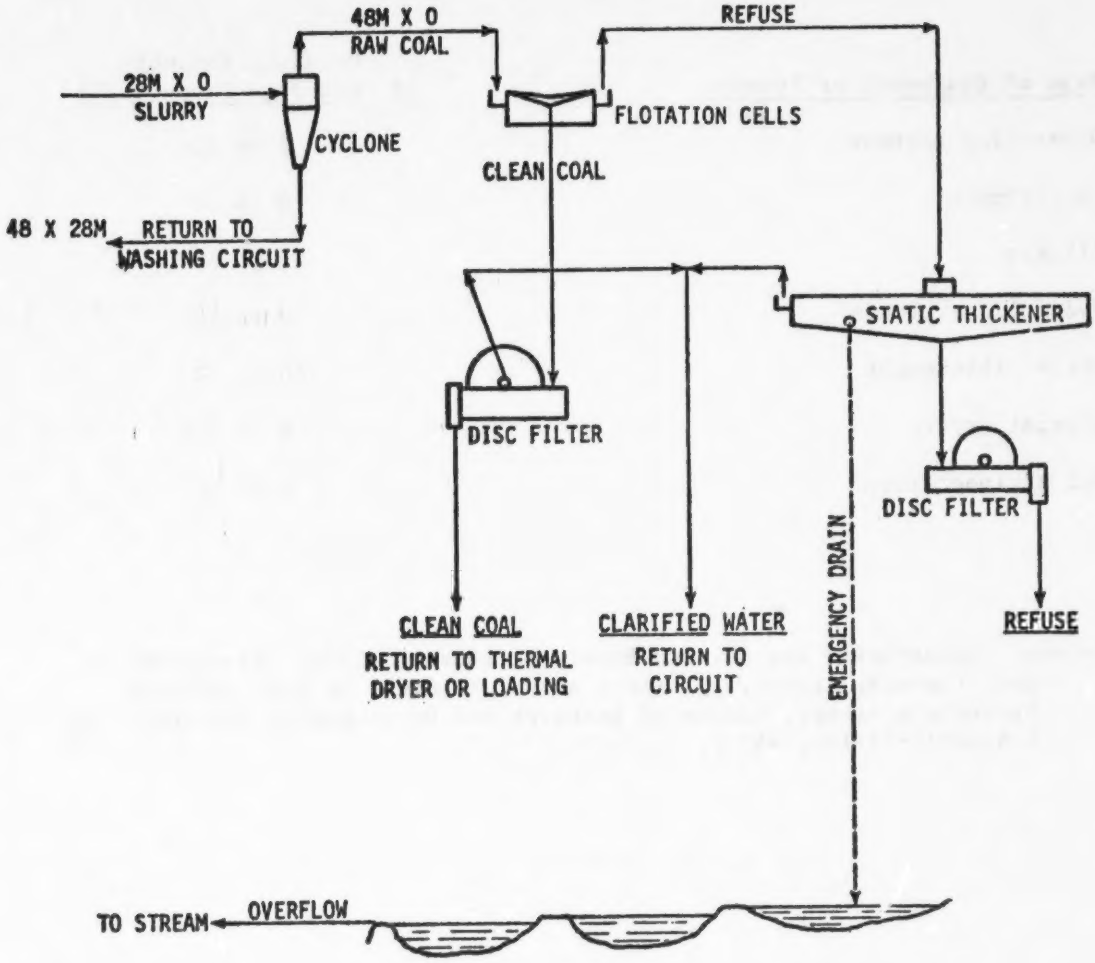

48M X 0
RAW COAL
REFUSE
28M X 0
SLURRY
CYCLONE
FLOTATION CELLS
CLEAN COAL
48 X 28M
RETURN TO
WASHING CIRCUIT
STATIC THICKENER
DISC FILTER
DISC FILTER
EMERGENCY DRAIN
CLEAN COAL
RETURN TO THERMAL
DRYER OR LOADING
CLARIFIED WATER
RETURN TO
CIRCUIT
REFUSE
TO STREAM
OVERFLOW

Figure 28. Typical product dewatering circuit for coal cleaning.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

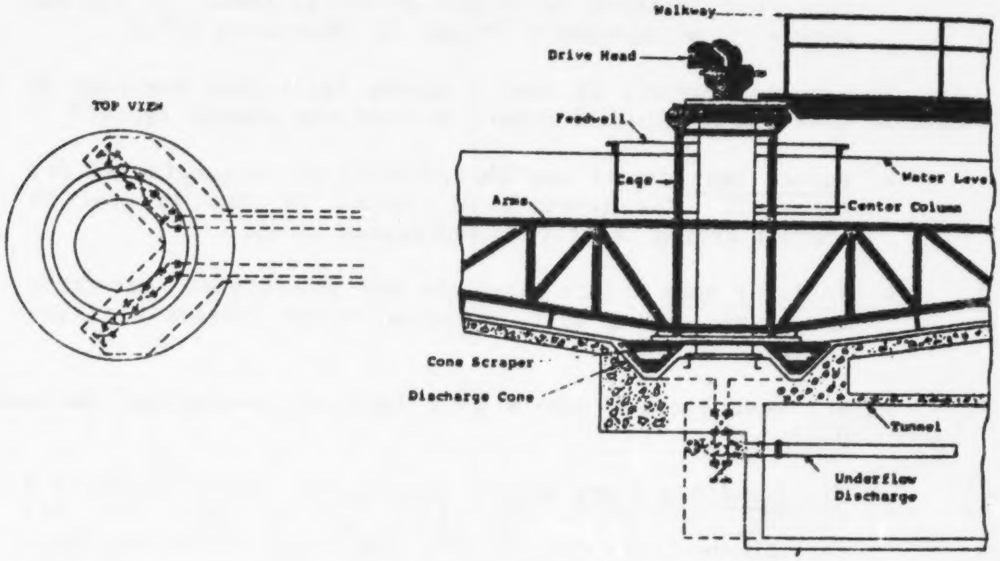

TOP VIEW
Walkway
Drive Head
Feedwell
Cage
Water Leve
Arms
Center Column
Cone Scraper
Discharge Cone
Tunnel
Underflow Discharge

Figure 29. Thickener vessel for dewatering of coal cleaning products. Sludge is withdrawn through the underflow discharge tunnel. Cleaned product exits through the upper tunnel.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

dewatering. The sieve bend, a typical dewatering and sizing screen, appears in Figure 30 (Nunenkamp 1976).

- Filters are of two types -- pressure and vacuum. Both types generally accept a feed with 30% solids at 27 dry MT (30 T) per hour. Pressure filters produce a cake with 20 to 23% moisture. Product cake from vacuum filters may contain 34 to 40% moisture. The moisture removal efficiency of the pressure filter is offset by its higher capital cost relative to vacuum filter systems. A typical vacuum filter appears in Figure 31 (Nunenkamp 1976).

Most thermal dryers at coal cleaning facilities use coal as the combustion feed stock. Thermal dryers include two general types.

- Direct heat dryers use the products of combustion to dry the coal. The direct heat concept is used in most US thermal drying facilities (Nunenkamp 1976).

- Indirect heat dryers circulate the products of combustion around the drying coal, avoiding direct contact with the coal.

Direct heat thermal dryers fall into six categories (McCandless and Shaver 1978):

- Fluidized bed dryer uses a constriction plate fitted to a housing that forces the drying air to pass uniformly through the plate (Figure 32). Feed coal enters the plate while hot air is lifted through the plate by a fan. The air currents thus produced cause the feed coal to float above the plate and flow toward the discharge point. Fine material is scrubbed from the exhaust gases, and the resultant residue reports to a thickening and dewatering step.

- Multilouver dryer comprises two concentric, revolving cylindrical shells, each fitted with louvers that support the bed of feed coal and direct it toward the discharge point. Multilouver dryers can handle large volumes of wet material that requires a relatively short drying time to minimize the potential for in-dryer combustion of the feed product.

- Rotary dryer consists of a solid outer cylinder and an inner shell of overlapping louvers that support and cascade the drying coal toward the discharge end. Drying action can be direct (using the products of combustion), or indirect (using an intermediate fluid for heat transfer between the shells).

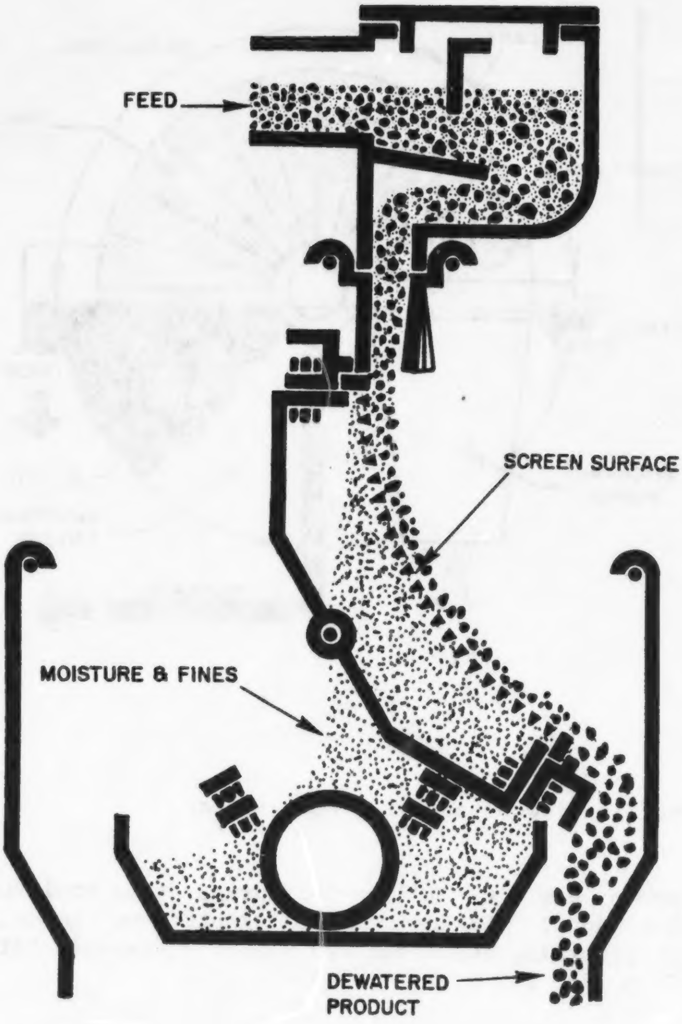

FEED
SCREEN SURFACE
MOISTURE & FINES
DEWATERED PRODUCT

Figure 30. Schematic profile of a sieve bend used for coal sizing and dewatering.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

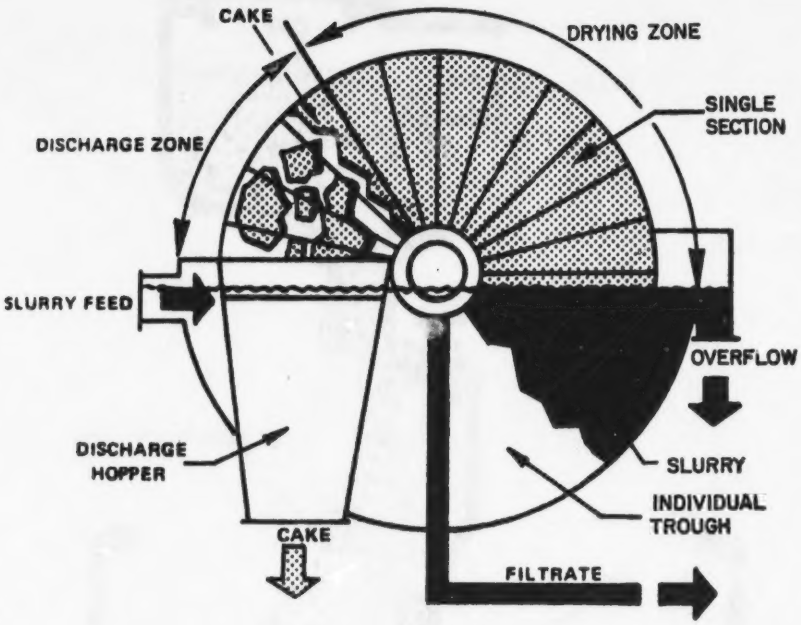

CAKE
DRYING ZONE
SINGLE SECTION
DISCHARGE ZONE
SLURRY FEED
OVERFLOW
DISCHARGE HOPPER
SLURRY
INDIVIDUAL TROUGH
CAKE
FILTRATE

Figure 31. Profile view of a coal vacuum filter.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

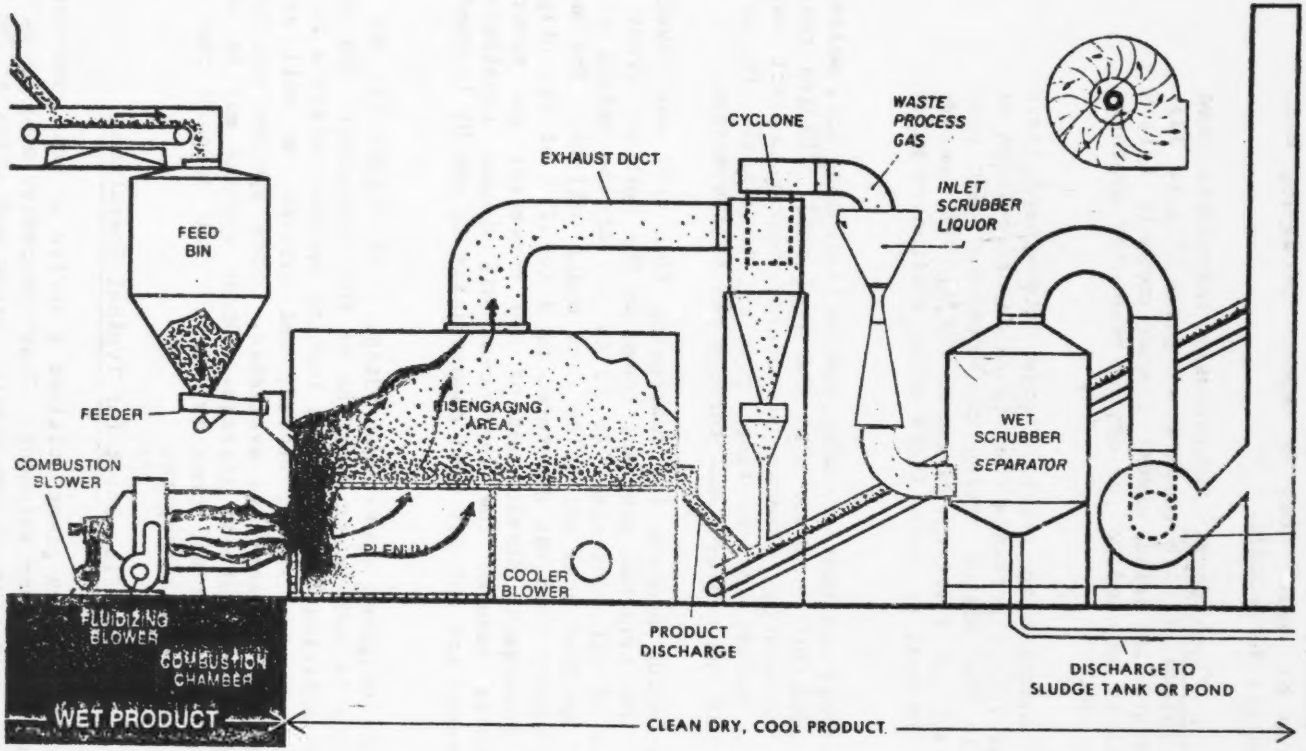

CYCLONE
WASTE PROCESS GAS
EXHAUST DUCT
INLET SCRUBBER LIQUOR
FEED BIN
FEEDER
DISENGAGING AREA
WET SCRUBBER SEPARATOR
COMBUSTION BLOWER
PLENUM
COOLER BLOWER
FLUIDIZING BLOWER
COMBUSTION CHAMBER
PRODUCT DISCHARGE
DISCHARGE TO SLUDGE TANK OR POND
WET PRODUCT
CLEAN DRY, COOL PRODUCT

Figure 32. Thermal dryer and exhaust scrubber.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

- Screen dryer applies gas pressure from combustion to squeeze the moisture mechanically from the feed coal through the supporting screens. A lower percentage of coal fines (relative to other drying processes) thus may be lifted from the bed. Coal is exposed to drying heat for approximately 50 seconds.

- Suspension or flash dryer continuously introduces feed coal into a column of high temperature gases (Figure 33). Surface moisture is dried almost instantaneously (flash dried). Coal is exposed to the drying gases for approximately 5 seconds.

- Turbo-dryer contains an inert nitrogen atmosphere (less than 3% oxygen) that prevents the explosion or ignition of coal fines in the sealed drying compartment. Wet coal enters a stack of rotating circular trays that successively feed the coal to lower trays using stationary wiper blades.

Indirect heat dryers use heat transfer agents (including oil, water, or steam) that do not come into contact with the feed coal. Drying coal is circulated through the heating chamber on covered conveyors that may be equipped with helical (worm) screws, fins, paddles, or discs. The drying fluid circulates around the conveyor and through the hollow screws.

The oil agglomeration process for dewatering fine coal was developed during World War I. The original process, known as the bulk oil Trent process, used an amount of oil equivalent to 30 to 50% of the weight of the coal to agglomerate the fine coal particles into small pellets. The pelletized, agglomerated slurry then was dewatered to 8 to 12 % of its original moisture content. Subsequent development of the convertol and spherical agglomeration processes reduced the in-process oil demand considerably, although these processes are not yet used commercially in the US (McCandless and Shaver 1978).

Coal storage and shipment operations (Stage 5 of Figure 19) are discussed more thoroughly in subsequent sections of this document. The degree of sophistication in individual storage and loading systems reflects in part the volume of coal being processed, stored, and shipped, as well as the kinds of coal transportation services available. Some systems can load a moving train directly from overhead storage. Other systems may be intermittent, using bucket loaders and dump trucks to feed hoppers that load trains either directly or via conveyors.

1.2.1.3.3. Process Flow Sheet for Typical Operations

The complete coal cleaning plant utilizes a series of unit processes to prepare ROM coal for storage and shipment. These processes must be mutually compatible for proper operation of the plant. Rates and sizes of feed for

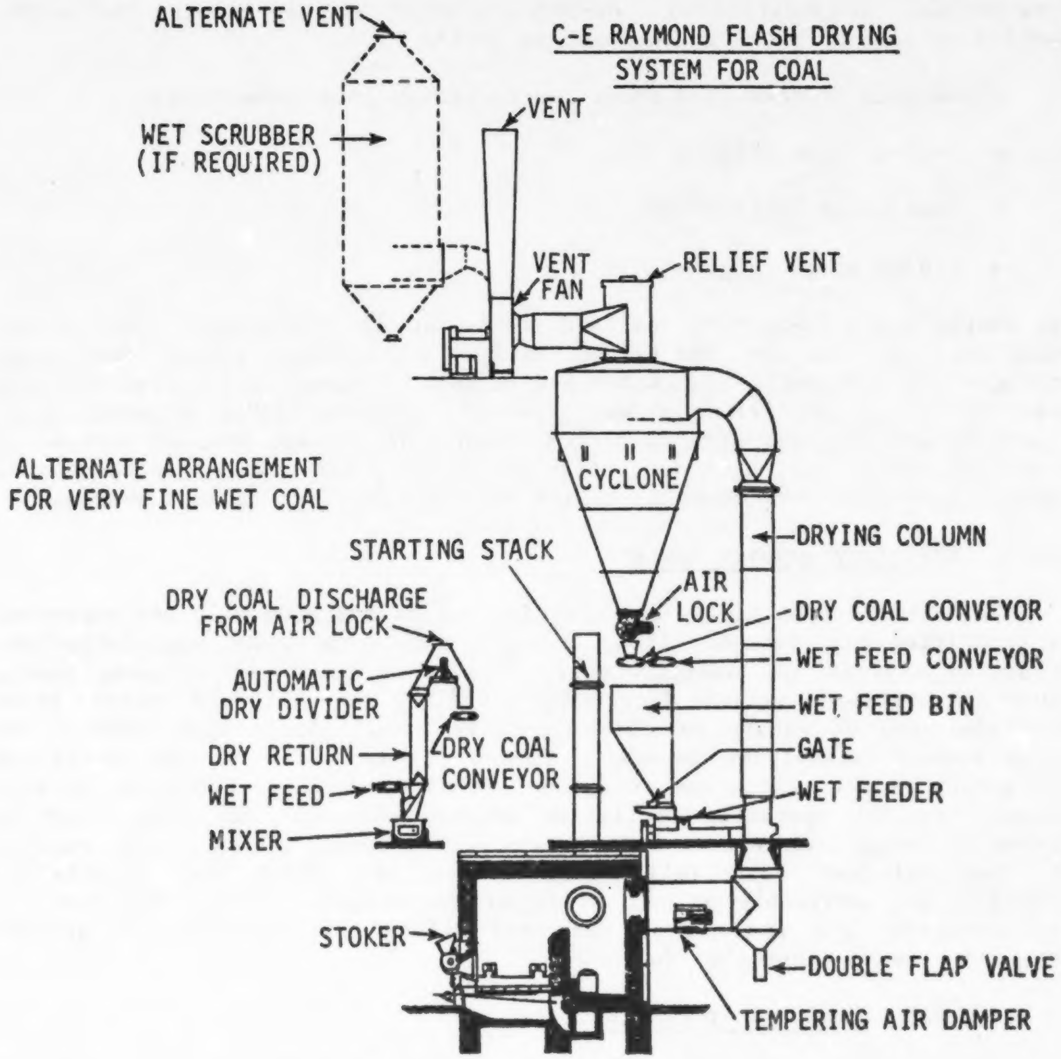

C-E RAYMOND FLASH DRYING SYSTEM FOR COAL
ALTERNATE VENT
WET SCRUBBER (IF REQUIRED)
VENT
VENT FAN
RELIEF VENT
ALTERNATE ARRANGEMENT FOR VERY FINE WET COAL
CYCLONE
DRYING COLUMN
STARTING STACK
AIR LOCK
DRY COAL DISCHARGE FROM AIR LOCK
DRY COAL CONVEYOR
WET FEED CONVEYOR
AUTOMATIC DRY DIVIDER
WET FEED BIN
DRY RETURN
DRY COAL CONVEYOR
GATE
WET FEED
WET FEEDER
MIXER
STOKER
DOUBLE FLAP VALVE
TEMPERING AIR DAMPER

Figure 33. Typical flash dryer.

Source: US Environmental Protection Agency. 1977. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

one unit process should compliment the capabilities of other in-line processes. Process water generally is recycled, especially in operations that use heavy media such as magnetite slurries for the separation of product from refuse. Evaporation and consumptive water use may require the introduction of make-up water to the process cycle.

A complete process flow sheet can be broken into three parts:

- Coarse stage (Figure 34)
- Fine stage (Figure 35)
- Sludge stage (Figure 36)

The coarse stage feeds fine coal and refuse to the fine stage. Coal slime, which includes fine coal and refuse, is fed to the sludge stage. Each stage produces characteristic blackwater and refuse. Process waters from the fine coal and sludge processing stages generally contain higher proportions of fines, especially clay-size particles, than coarse stage process waters. A series of thickeners, cyclones, screens, filters, and dryers may be used to recover a maximum percentage of solids from the recycled process waters.

1.2.2. Auxiliary Support Systems

Underground coal mining and cleaning operations generally are supported by facilities for transportation, storage, maintenance, and administration. Maintenance yards and administrative facilities (such as changing rooms, first aid stations, and the dispatcher's office) generally are located in or near the area of mining or cleaning operations. Space requirements for these support activities generally depend on the sizes of the operations which they serve. Large operating facilities may require extensive service areas. Smaller operating facilities located near to one another may be served by common maintenance and administrative areas, although some administrative services (especially mine rescue and first aid facilities) generally are available at all sites of operations. Facilities for the transportation and storage of coal and refuse are described in greater detail in the sections that follow.

1.2.2.1. Coal Transportation

The US Department of Energy (USDOE) reports statistics for six modes of coal transportation (USDOE 1979). During 1978, approximately 550 million MT (600 million T) of coal (93% of total production) were delivered to US consumers via these transportation networks (Table 11). The remaining production was either exported (6%) or stockpiled (1%). The conveyance systems that are used for the transport of coal from mines to cleaning facilities, stockpiles, and consumers include railroads, barges, trucks, conveyors, tramways, and slurry pipelines.

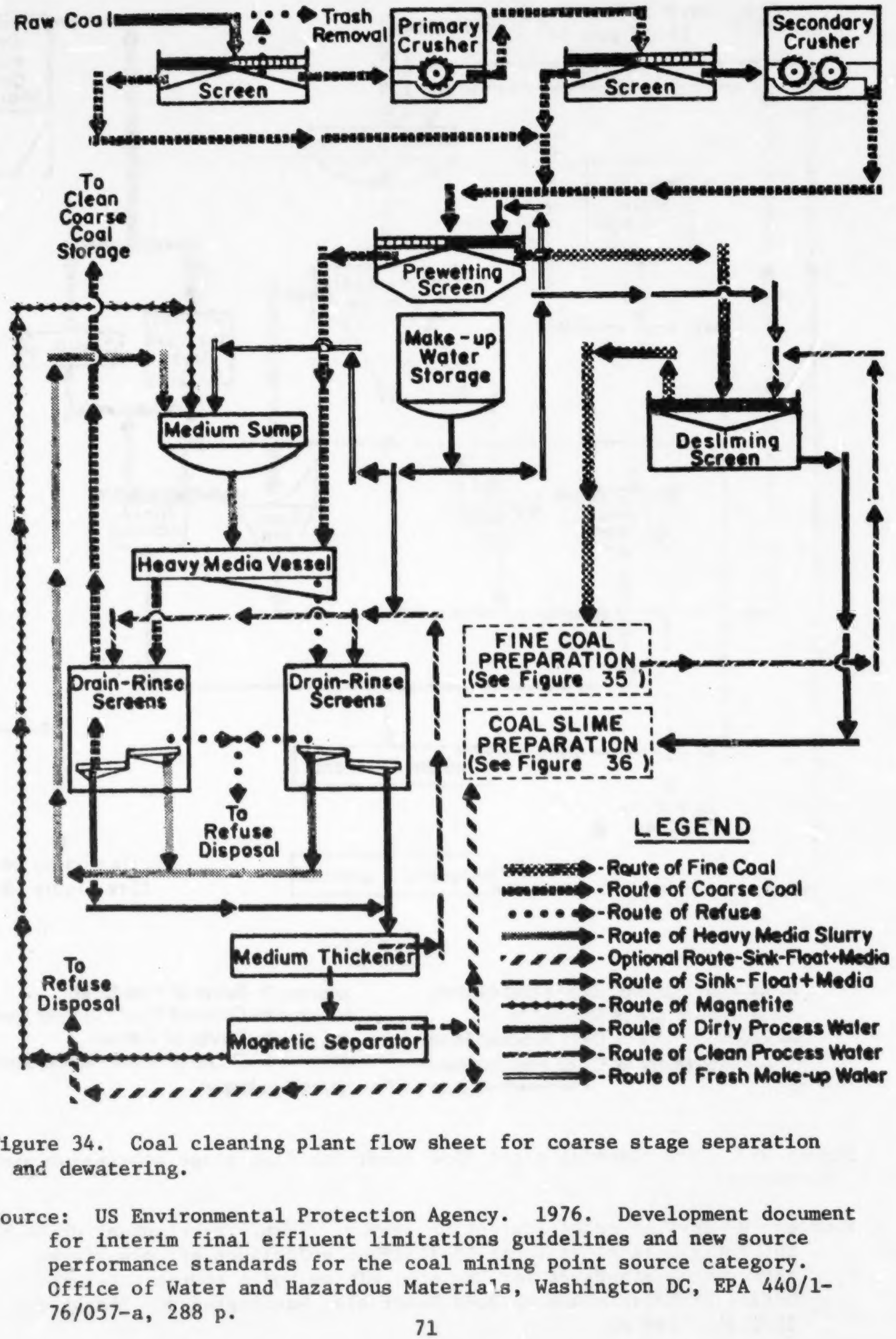

Raw Coal
Trash Removal
Primary Crusher
Screen
Screen
Secondary Crusher
To Clean Coarse Coal Storage
Prewetting Screen
Make-up Water Storage
Medium Sump
Desliming Screen
Heavy Media Vessel
FINE COAL PREPARATION (See Figure 35)
COAL SLIME PREPARATION (See Figure 36)
Drain-Rinse Screens
Drain-Rinse Screens
To Refuse Disposal
Medium Thickener
To Refuse Disposal
Magnetic Separator
LEGEND
-Route of Fine Coal
-Route of Coarse Coal
-Route of Refuse
-Route of Heavy Media Slurry
-Optional Route-Sink-Float+Media
-Route of Sink-Float+Media
-Route of Magnetite
-Route of Dirty Process Water
-Route of Clean Process Water
-Route of Fresh Make-up Water

Figure 34. Coal cleaning plant flow sheet for coarse stage separation and dewatering.

Source: US Environmental Protection Agency. 1976. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Materials, Washington DC, EPA 440/1-76/057-a, 288 p.

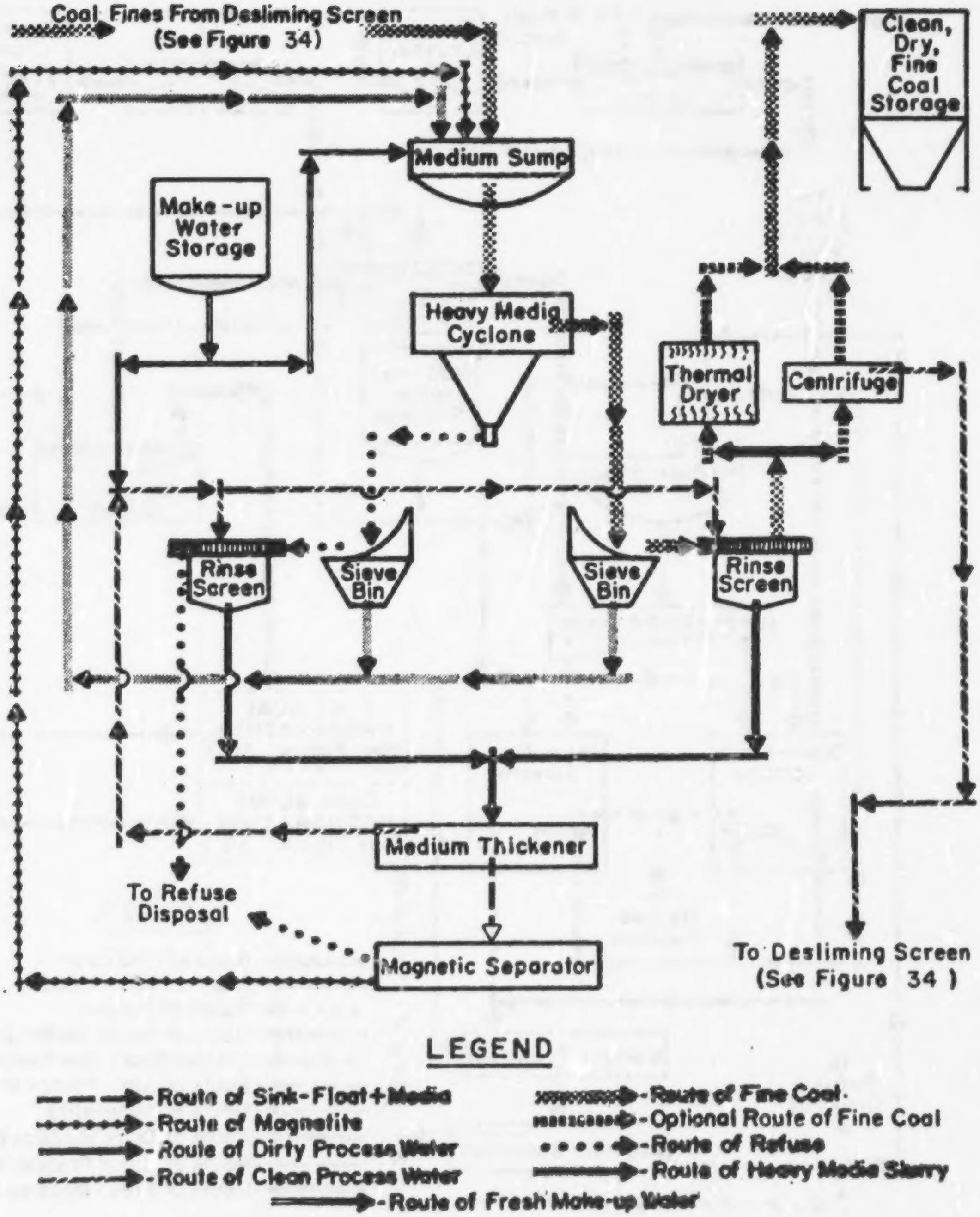

Coal Fines From Desliming Screen
(See Figure 34)
Clean, Dry, Fine Coal Storage
Medium Sump
Make-up Water Storage
Heavy Media Cyclone
Thermal Dryer
Centrifuge
Rinse Screen
Sieve Bin
Sieve Bin
Rinse Screen
Medium Thickener
To Refuse Disposal
Magnetic Separator
To Desliming Screen
(See Figure 34)
LEGEND
Route of Sink-Float+Media
Route of Magnetite
Route of Dirty Process Water
Route of Clean Process Water
Route of Fine Coal
Optional Route of Fine Coal
Route of Refuse
Route of Heavy Media Slurry
Route of Fresh Make-up Water

Figure 35. Coal cleaning plant flow sheet for fine stage separation and dewatering.

Source: US Environmental Protection Agency. 1976. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Materials, Washington DC, EPA 440/1-76/057-a, 288 p.

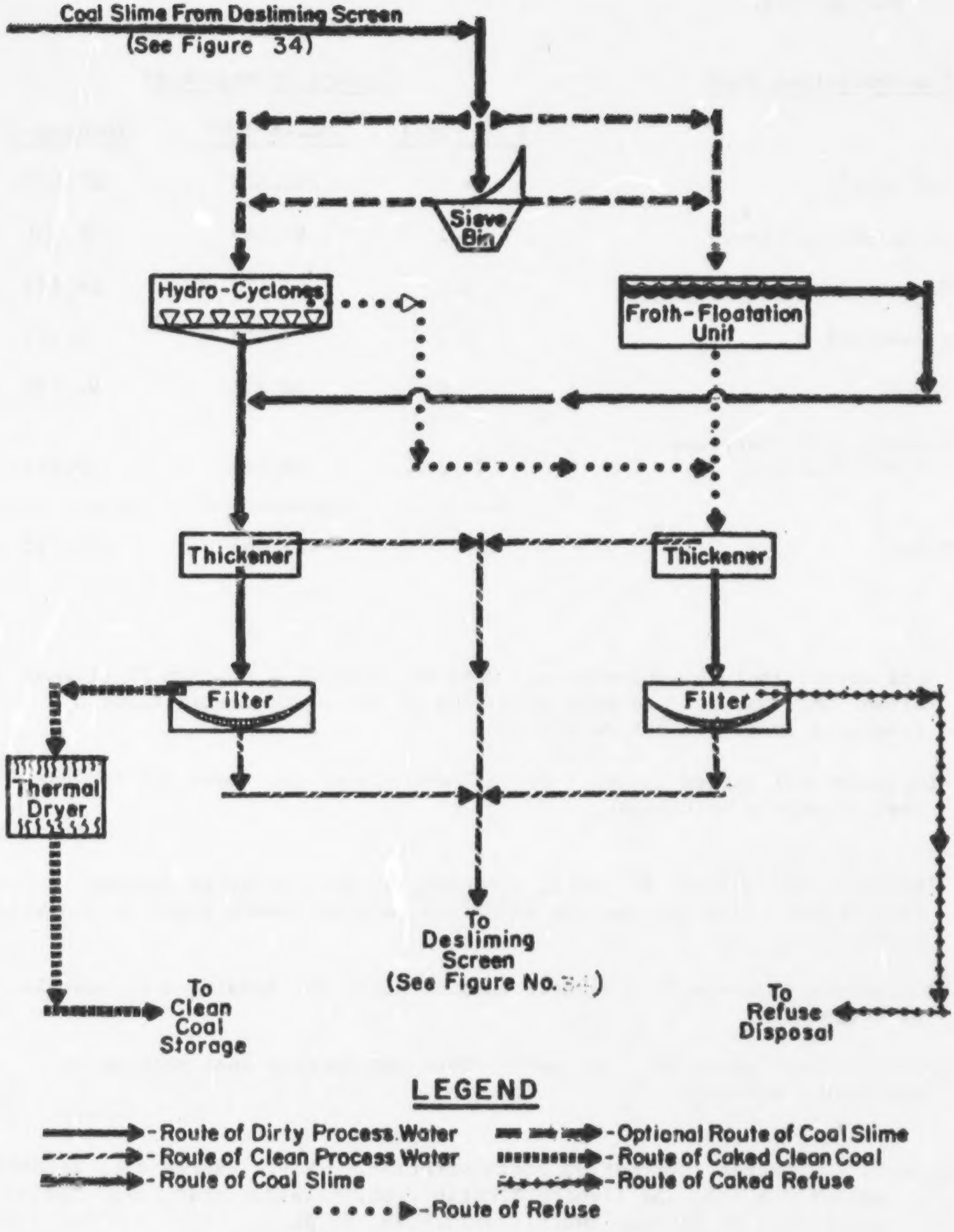

Coal Slime From Desliming Screen
(See Figure 34)
Sieve Bin
Hydro-Cyclones
Froth-Floatation Unit
Thickener
Thickener
Filter
Filter
Thermal Dryer
To Clean Coal Storage
To Desliming Screen
(See Figure No. 34)
To Refuse Disposal
LEGEND
-Route of Dirty Process Water
-Route of Clean Process Water
-Route of Coal Slime
-Optional Route of Coal Slime
-Route of Caked Clean Coal
-Route of Caked Refuse
-Route of Refuse

Figure 36. Coal cleaning plant flow sheet for sludge (slime) separation and dewatering.

Source: US Environmental Protection Agency. 1976. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Materials, Washington DC, EPA 440/1-76/057-a, 288 p.

Table 11. Transportation modes for coal produced and consumed in the US during 1978.

Transportation Mode	Tonnage Transported[1]		
	% of Total	Thousand MT	Thousand T
All rail[2]	54.0	293,415	323,500
River and ex-river[3]	16.1	87,345	96,301
Great lakes	2.7	14,670	16,175
Tidewater[4]	0.6	3,458	3,813
Truck[5]	15.6	84,832	93,530
Tramway, conveyor, and private railroad	11.0	59,765	65,893
TOTAL	100	543,485	599,212

[1] Data do not include approximately 0.45 million MT (1 million T) of coal either that was sold to mine employees or for which destinations and transport modes are not revealable.

[2] Includes coal hauled to and from railheads by truck. Does not include coal moved via waterways.

[3] Includes coal shipped by truck, conveyor, or rail to barge loading facilities. Does not include shipments to Great Lakes ports or tidewater ports.

[4] Includes coal moved to tidewater dumping piers for loading into vessels as cargo.

[5] Includes coal moved by truck only. Does not include coal shipped by additional methods.

Source: US Energy Information Administration. 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, DOE/EIA-0125/4Q78, 85 p.

1.2.2.1.1. Railroads

Three kinds of trains were used to transport approximately 54% of the coal produced and consumed in the US during 1978 (USEIA 1979).

- Conventional trains haul coal as common freight. Coal cars are treated like all other freight cars, and are subject to the full tariffs of the Interstate Commerce Commission (ICC).
- Unit trains comprise approximately 100 coal cars, each with a 91 MT (100 T) capacity. These trains are subject to approximately two thirds of the full ICC tariff.
- Dedicated trains generally use tracks that are constructed solely for transporting coal to and from coal mining or processing facilities that otherwise would be without rail service.

The choice of a coal car loading system for an individual coal mining or cleaning facility depends on the kinds of trains to be loaded. Two general kinds of systems normally are used.

- Plant-rate loading systems use booms and chutes to load the output from a coal cleaning plant directly to waiting coal cars. This method generally is applicable to single car loadings although it also is used for loading unit trains at some operations.
- Flood loading systems are utilized to load most unit trains. Moving coal cars are loaded by chutes fed from overhead storage silos or remote stockpiles. At some operations, conveyors may transfer the coal to overhead silos from the cleaning plant directly, or the silo may be loaded from remote stockpiles. The routing of coal from plant to stockpile to loading facility generally is a function of train availability and the production rate at the plant.

Two kinds of dumping systems are used to unload coal from rail cars. The type of system utilized at a particular site depends on the type of car to be dumped (Mining Informational Services 1977).

- Bottom-dump cars unload coal through dump gates located in the decks of the cars. The coal falls into chutes or hoppers located beneath trestles. The cars may be unloaded while stationary or in motion, with or without car vibrators to shake the coal through the gates.

- Rotary dump cars can be unloaded by one of two methods, depending on car construction. Most of the coal cars that are used in conventional trains are of random size and construction, and must be uncoupled for individual rotation. Unit train cars are of uniform size, and are equipped with a swivel coupling at one end for individual rotation without uncoupling.

1.2.2.1.2. Barges

During 1978, barges transported 16.1% of the coal produced and consumed in the US (Table 11). Coal barges generally are towed in strings of 10 to 36. The length of a string of barges depends on the sizes of locks and the depths of navigation channels of an individual waterway. Most modern barges are of open-hopper design; the coal is transported uncovered. Coal barges range in capacity between 900 and 1,800 MT (1,000 and 2,000 T; Szabo 1978).

Coal usually is transported to barge-loading facilities via train. Coal cars are unloaded by bottom-dump or rotary-dump systems (Section 1.2.2.1.1.). Conveyors and buckets transfer the coal from dump-piles, stockpiles, bins, silos, or other load-staging areas. Five classes of barge-loading facilities are used nationwide (Szabo 1978).

- Simple dock, in which trucks dump directly to the barges at dockside
- Stationary chute in which a string of moving barges is flood-loaded from a fixed loading chute
- Elevating boom, which can be adjusted to compensate for changes in river stage as it loads a moving string of barges
- Floating boom, in which the loading boom is mounted on a floating barge so that the boom can pivot across a string of barges
- Tripper-conveyor, in which the loading chute moves back and forth across the stationary string of barges.

Unloading facilities for barges generally include docks, stockpiles, outbuildings, service areas, and access roads. Unloading facilities may be located at existing ports or near power generating stations along navigable river corridors. Coal is unloaded from barges using (1) clamshell buckets operated from individual cranes, or (2) a continuous bucket unloading system with buckets mounted on a chain drive and feeding the off-loaded coal to conveyors.

1.2.2.1.3. Trucks

Trucks transported 15.6% of the coal produced and consumed in the US during 1978. Trucks primarily are used to transport coal over short distances from mines to cleaning plants or other nearby collection points. Capacities of coal trucks generally range between 18 and 27 MT (20 and 30 T), although off-road coal haulers may exceed 154 MT (170 T) capacity.

Efficient transportation of coal by truck requires properly constructed and maintained haul roads. Haul road alignments are chosen from optimal combinations of machine-related factors such as horsepower-load ratios and acceptable rates of tire wear, and environmental factors such as topography, slope stability, and surface water drainage patterns. The environmentally protective features of haul road design (culverts, bridges, stormwater drainage ways, and maximum grade) may reduce the costs of roadway and machinery maintenance by minimizing the road surface deterioration ordinarily caused by stormwater erosion and poor vehicle traction on wet or unstable soils and excessive grades (Grim and Hill 1974, USEPA 1976b). Haul roads are regulated under the regulatory programs administered by the USOSM (Section 1.6.3.).

1.2.2.1.4. Conveyors and Tramways

Conveyors generally carry coal for distances of 30 to 60 m (100 to 200 ft) between process steps and storage and loading facilities (Szabo 1978). Conveyor systems longer than 1 km (0.6 mi) are unusual, although conveyors of several kilometers length are used successfully at present (USDOE 1978). The capacity of a conveyor system can be increased by adding one or more tiers of belts to a line of pylons (Chironis 1978).

Aerial tramways utilize buckets attached to steel cables to transport coal, refuse, and personnel over rough terrain and areally extensive obstacles. The cables are suspended from pylons and towers. Lengths of tramways generally are characterized in hundreds of meters, although some systems now in operation exceed 50 km (30 mi).

Tramway systems may be reversible or non-reversible. Reversible systems return the carriers to their points of origin by reversing the direction of travel on load-pulling cables. Non-reversible systems return the carriers utilizing either separate lengths of cable or the returning portion of a continuous cable. The types of aerial tramways currently used include:

- Monocable -- A single cable is spliced into a continuous loop that simultaneously supports and pulls the buckets.
- Bicable -- One cable is fixed between two points and serves as a track for buckets that are pulled by a second cable system which may operate as a continuous loop.
- Twin cable -- A pair of track cables may be utilized in monocable and bicable systems to provide separate haulage

for loaded and empty buckets, usually suspended from opposite sides of the supporting towers (Cummins and Given 1973).

1.2.2.1.5. Coal Slurry Pipelines

The only coal slurry pipeline presently in operation (USDOE 1978b) has the capacity to transport 4.5 million MT (5 million T) of coal per year from the Black Mesa coal field in Arizona to the Mohave electric generating station in Nevada, a distance of 437 km (273 mi; Szabo 1978). Additional pipelines currently are planned or under construction (Section 1.3.).

Slurry pipeline systems are designed for lifespans of 20 to 40 years (Cummins and Given 1973). To be economically successful, a coal slurry pipeline generally must transport at least 3.6 million MT (4 million T) per year. Reductions in the costs of other coal transport systems may affect the operation of a pipeline system years after the system is completed. A 174 km (108 mi) long coal slurry pipeline that began transporting coal during 1957 was furloughed from use indefinitely during 1963 because of adjustments in ICC tariff structures for coal transport by rail that made the pipeline uncompetitive (Chironis 1978). The pipeline carried 0.9 million MT (1 million T) of coal per year across the Ohio countryside from a mine near Cadiz to the electric generating facility at Eastlake (Szabo 1978).

The major components of a coal slurry pipeline system include a preparation plant, pumps, pipeline, storage tanks, and dewatering facilities. Component operations are computerized and can be monitored and adjusted telemetrically by a single operator at a centralized control station. At the Black Mesa operation, the coal slurry preparation plant performs crushing and sizing operations similar to those described for coal cleaning facilities in Section 1.2.1.3. Coal is crushed and screened to produce a particle size and density distribution of fine coal that mixes effectively with water to form a slurry containing an average of 47% solids by weight. The slurry is stored temporarily in large tanks equipped with agitators that keep the fine coal in suspension.

Slurry is pumped from the tanks to the pipeline at approximately 545 MT (600 T) per hour. To sustain its annual delivery rate of 4.5 million MT of coal per year, the Black Mesa pipeline requires approximately 450 million liters (120 million gal) of water per year (assuming that 1 MT of water occupies 1,000 l).

At the generating station, the slurry again is stored in agitated tanks for the dewatering process. The slurry is centrifuged to remove approximately 30% of the water. The coal cake is pulverized and fed to the generating station at 20% moisture. Centrifuged water is clarified and then circulated through the generating station cooling system or pumped to large evaporation ponds. No water discharge is permitted from the Black Mesa operation (Szabo 1978).

1.2.2.2. Storage Facilities

Coal and coal refuse are stockpiled in enclosed or open air storage facilities. Enclosed facilities for cleaned coal include silos and bins. Coal refuse historically has been stored in abandoned mine workings (Section 3.4). Open air storage facilities for coal and coal refuse are described below.

1.2.2.2.1. Coal Stockpiles

Approximately 5.5 million MT (6 million T) or 1% of the Nation's annual coal production was stockpiled during 1978 (USEIA 1979), mostly at coal consuming facilities or at centralized distribution points. Haulage for coal generally is the rate-limiting factor for production at underground mines. The amount of coal stockpiled in conjunction with mining operations, therefore, is minimal (Cummins and Given 1973). At coal cleaning facilities, ROM coal is stockpiled to maintain even rates of feed to preparation plants. Stockpiles of cleaned coal generally contain the equivalent of 0.5 hour of rated plant cleaning capacity to assure the cost-effective blending and loading of the final product (Nunenkamp 1976).

The storage capacity of a coal stockpile is determined by the shape and angle of repose of the stockpiled material. The shape of a stockpile is a function of the pile-stacking mechanism. Ramped stockpiles are formed by trucks. Shapes of ramped stockpiles therefore vary widely. Stockpiles also are stacked by booms mounted with conveyors or buckets. These stackers produce three general stockpile shapes.

- Conical stockpiles are formed by fixed stackers.
- Rectangular stockpiles are formed by traveling stackers mounted on fixed rails.
- Kidney-shaped stockpiles are formed by stackers that pivot at the loading end (Cummins and Given 1973).

Coal is reclaimed from stockpiles by surface and subsurface systems. The shape of the stockpile determines the kind of system employed.

- Surface systems include traveling stackers that reclaim the coal from rectangular stockpiles. These systems are used for open-air blending of coal. Extensive stacker-reclaimer operations offer the advantage of nearly 100% live storage, but also can produce considerable amounts of fugitive dust.
- Subsurface systems include conveyors or buckets that reclaim coal from the centers of conical-, rectangular-, or kidney-shaped piles. The conveyors and buckets are fed

by chutes and hoppers that are located to afford maximum live storage capacity with minimal surface handling.

1.2.2.2.2. Coal Refuse Piles

Coal refuse includes the coarse material extracted during mine development and the coarse and fine reject from coal cleaning operations (Section 2.1.1.3.). Methods for the disposal of coal refuse generally depend on (1) the physical and chemical characteristics of the refuse material (i.e. particle size distribution, moisture content, and the occurrence of toxic and acid-forming elements), (2) the volume of refuse to be stored, and (3) the proximity of suitable storage sites to the coal mining and cleaning operations.

Coal refuse may require dewatering, treatment, or temporary storage prior to its ultimate disposal. Coarse refuse that is free from excessive moisture may have sufficient mechanical stability to form temporary open air stockpiles without impoundments (Section 1.2.2.2.). These stockpiles are reclaimed as the coarse refuse is buried in a separate landfill. Stockpiling may be necessary to facilitate the blending of coarse refuse with dewatered fine coal refuse to produce a homogeneous refuse product with more desirable physical and chemical properties than existed in the raw refuse materials singly (Cowherd 1977).

The amount of coal refuse produced by a cleaning facility may range between 20% and 40% of its ROM feed coal (Nunenkamp 1976). Coal refuse generally is denser and therefore requires less volume per unit weight for storage than cleaned coal. The proportion of fine and coarse refuse that is available for disposal from a coal cleaning operation generally is a function of the objectives and complexity of the cleaning process. Multiple stage preparation plants with separate fine and coarse coal cleaning circuits generally produce more fine wastes as a separate product than do single-stage sizing and crushing operations.

The selection of a coal refuse disposal site generally is based on the consideration of environmental, engineering, and cost factors. Two kinds of sites currently are in use for permanent or long-term storage of coal refuse:

- Dump -- a landfill on or in the earth for the storage of relatively dry refuse
- Impoundment -- a depression or excavation on or in the earth for the storage of fluid refuse.

The topography of the disposal site usually restricts the choice of possible disposal site configurations. Five types of dumps and four types of impoundments are recognized for use in generalized topographic situations (W. A. Wahler and Associates 1978). The types include:

- Dumps (Figure 37)

  - Type I: Valley fills are common in hilly or mountainous terrain. The refuse pile has a horizontal or sloping surface that is extended down the valley in compacted lifts. The disposal site eventually fills the valley.

  - Type II: Cross-valley fills are similar to Type I fills but do not completely fill the valley. This type of fill often is used to construct the dam for a Type VII impoundment.

  - Type III: Side-hill fills generally are constructed on gently sloping, stable terrain. If the fill crosses a stream or a large topographic depression, it may be classed as a valley fill.

  - Type IV: Ridge piles straddle a ridgeline or the nose of a ridge. This type of fill is not in common use, although some ridge piles have been constructed on gently sloping, stable terrain.

  - Type V: Waste heaps generally are utilized in the flat terrain of the midwest. Waste heaps may be constructed by the same kinds of systems used for the stockpiling of clean coal.

- Impoundments (Figure 38)

  - Type VII: Cross-valley slurry ponds are formed by embankments that traverse the valleys from ridge to ridge. Coarse coal refuse often has been used for construction of cross-valley impoundments.

  - Type VIII: Side-hill ponds are constructed on gentle, stable slopes of wide valleys. The impoundment is formed by a three-sided embankment or dike.

  - Type IX: Dike ponds generally are used in flat terrain. The encircling embankment excludes drainage into the impoundment from outside areas.

  - Type X: Incised ponds are formed by excavation of the land surface, usually in conjunction with surface development operations of underground mines or combined surface and underground mining operations.

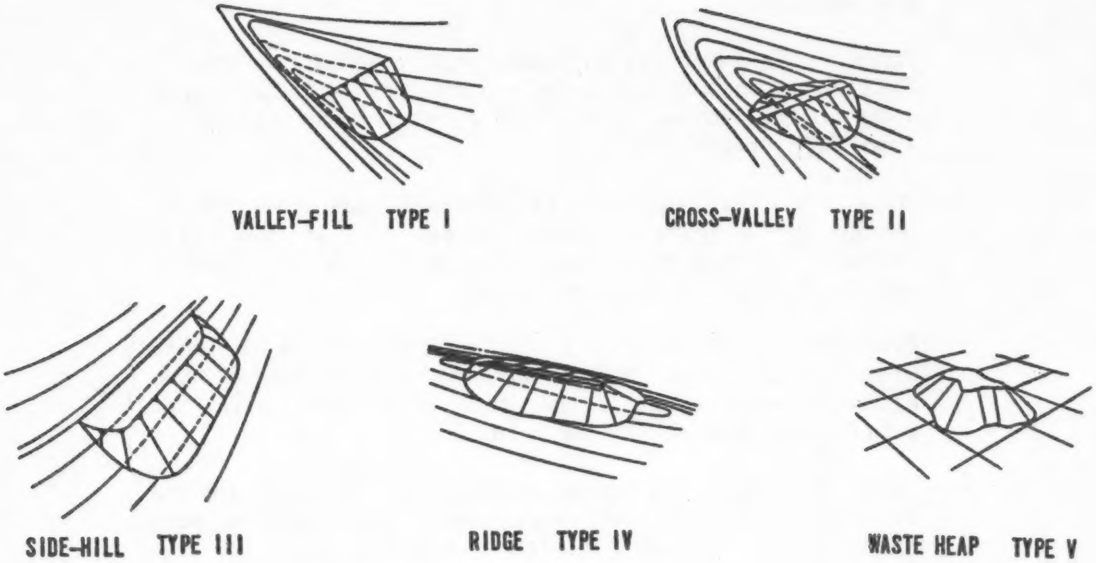
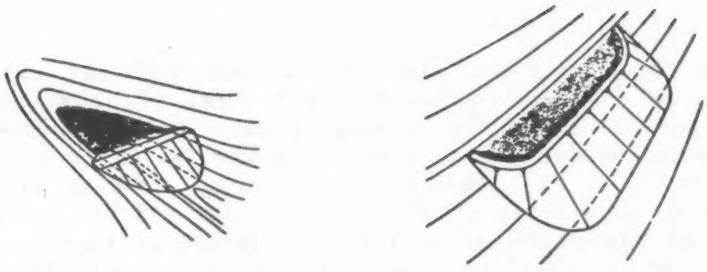

VALLEY-FILL TYPE I
CROSS-VALLEY TYPE II
SIDE-HILL TYPE III
RIDGE TYPE IV
WASTE HEAP TYPE V

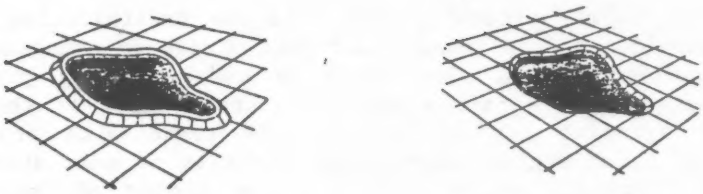
Figure 37. Coal refuse dump types.

Source: W. A. Wahler and Associates. 1978. Pollution control guidelines for coal refuse piles and slurry ponds. Prepared for US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-222, 214 p.



CROSS-VALLEY TYPE VII

SIDE-HILL TYPE VIII



DIKED POND TYPE IX

INCISED POND TYPE X

Figure 38. Coal refuse impoundment types.

Source: W. A. Wahler and Associates. 1978. Pollution control guidelines for coal refuse piles and slurry ponds. Prepared for US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-222, 214 p.

Type VI dumps and Type XI impoundments account for the more complex configurations of disposal sites that represent combinations of the other types.

Specifications for the construction of dumps and impoundments for coal refuse are established under the regulatory program administered by the USOSM (Section 1.6.3.). Guidelines for the selection and operation of coal refuse disposal sites are described in Section 3.4.1.

1.3. TRENDS

Trends in the mining and cleaning of coal reflect: (1) Federal and State legislative and administrative activities, (2) advancement of coal technologies, and (3) the changing role of other energy sources in meeting current and future needs. These trends are manifested in (1) the emerging role of western coal, (2) technological changes in coal mining and processing resulting in overall gains in efficiency, and (3) pollution control requirements and environmental performance standards that reflect concern for the potentially adverse environmental effects of coal mining activity.

1.3.1. Locational Changes

Public managers are assessing the costs and feasibilities of technologies to halt subsidence from underground coal mining in numerous eastern and midwestern urbanized areas. The trend in modern mining practice is to locate new underground coal mines away from urban areas to the extent possible. State agencies may accelerate this trend with prohibitions or restrictions on the siting of underground mines in or near developed areas. USDOI agencies currently are re-examining the impact of underground coal mining in undeveloped areas (Dunrud and Osterwald 1978).

Coalfields east of Mississippi River account for approximately 55% of demonstrated coal reserves (USBOM 1978) and approximately 97% of all US underground mines (Hittman Associates, Inc. 1976). Most coal cleaning operations also are located east of Mississippi River. There are no changes forecast for this trend; most new western coal production will come from a few large surface mines (USDOI 1978).

1.3.2. Raw Materials and Energy

The raw materials that are used in underground coal mining operations include chemicals for pollution control and blasting; heavy, inert rock dust for the suppresion of lighter, explosive coal dust; water for dust control; and process-related materials such as roof bolts, roof timbers, and brattice cloth. The development of improved technologies for underground blasting and roof support have contributed to the improved safety of underground coal mines. Small subsidiary gains in the efficiencies of underground coal-mining techniques may be attributable in part to these safety-related improvements.

Most underground mining equipment is powered electrically either by batteries or with generating equipment located at the surface. The UMWA continues to resist the introduction of diesel-powered equipment underground, although such equipment now is used in several non-union underground coal mines. Studies indicate that much underground mining equipment has excessive horsepower, although this condition may be corrected as operators of new mines use computer simulation techniques to match equipment performance characteristics with actual power requirements (Hittman Associates, Inc. 1976).

The energy required to mine, clean, and transport coal has been estimated based on a study conducted by Hittman and Associates, Inc. (1974). The data that are listed in Table 12 show the nationwide average Btu-equivalent of coal that is mined, cleaned, or transported per Btu of energy that is expended to mine, clean, or transport the coal. These data are considered accurate to within one order of magnitude. This analysis is based on the assumption that one kg (2.2 lb) of coal is equivalent to 26,800 Btu.

Longwall mining systems generally utilize equipment with higher total energy consumption requirements than room and pillar systems. As a result, longwall systems extract equivalent amounts of coal at approximately 10 times the energy cost of room and pillar operations, although longwall systems use fewer men and achieve higher levels of output per man shift than room-and-pillar systems. Longwall systems also maximize recovery of the coal resource.

During coal cleaning operations, most of the total process energy requirement occurs during primary crushing. Subsequent sizing, crushing, and separating functions require approximately 10% of the energy expended for primary crushing. The energy required by thermal dryers varies considerably with dryer design and throughput rate.

The choice of one coal transportation mode over another generally is based on the cost and availability of a carrier and the compatibility of the transport system with site constraints and operating conditions. Unit trains are highly favored for the transport of large amounts of coal on a continuing basis, although unit trains expend more energy than other transportation modes to haul equivalent amounts of coal.

1.3.3. Process

1.3.3.1. Underground Coal Mining

Developments in underground coal mining technology have focused on reversing the trend toward decreasing productivity per man shift which is attributed to more stringent safety regulations and labor relations problems in the bituminous coal industry. The increased use of longwall mining may result in higher productivity, but longwall systems operate efficiently only in near-ideal conditions of continuous seam height; firm, dry bottom; and

Table 12. Energy requirements of selected underground coal mining, cleaning, and transportation methods.

Operation	Btu's of coal energy mined, processed or transported per Btu of energy expended
Underground mining	
Longwall	180
Room and pillar	1,160
Coal cleaning	
Primary crushing	6,250
Combined crushing and sizing	560
Thermal drying	1,320
Transportation	
Unit train	70
Mixed train	89
Barge	129
Slurry pipeline	141
Trucks	1,090
Conveyors	2,624

Source: Hittman Associates, Inc. 1974. Environmental impacts, efficiency, and costs of energy supply and end use: Volume 1. Prepared for the Council on Environmental Quality, the National Science Foundation and the US Environmental Protection Agency, Columbia MD, variously paged.

overburden which subsides properly and completely when roof supports are removed. Shortwall mining systems require less intensive capital investment than longwall systems and therefore may receive closer scrutiny in future (USDOE 1978b).

1.3.3.2. Coal Cleaning

The quest for higher productivity has accelerated the use of continuous mining systems in place of conventional drill and blast operations, often resulting in a ROM coal that contains increased fines and non-combustible material. Machine-mined coals generally need more intensive processing before they are suitable for modern boilers and blast furnaces.

A new family of chemical coal cleaning technologies is being developed that reduces both the pyritic and organic sulfur contents of processed coals. These technologies are expected to receive widespread commercial use in the high-sulfur coal fields of the Eastern and Interior Coal Provinces. In the brief technology descriptions that follow, process sponsors are shown in parentheses (McCandless and Shaver 1978).

- Magnex process treats dry, pulverized coal with $Fe(CO)_3$, allowing up to 90% of the pyritic sulfur content to be removed magnetically (Hazen Research, Inc., Golden CO).

- Syracuse process comminutes coal by exposure to NH_3 vapor. Conventional cleaning processes then treat coal and ash to remove 50 to 70% of the pyritic sulfur content (Syracuse Reasearch Corp., Syracuse NY).

- Meyers process uses $Fe_2(SO_4)_3$ and oxygen in water to remove 90 to 95% of the pyritic sulfur content by oxidative leaching (TRW, Inc., Redondo Beach CA).

- LoI process uses oxygen in water at moderate temperatures and pressures to remove 90 to 95% of the pyritic sulfur content by oxidative leaching (Kennecott Copper Co., Edgemont MT).

- Perc process removes 95% of the pyritic and up to 40% of the organic sulfur content of coal using air oxidation and water leaching at high temperatures and moderate pressures (US Department of Energy, Bruceton PA).

- GE process uses microwave treatment of coal permeated with NaOH to convert pyritic and organic sulfur to soluble sulfides. Approximately 75% of the total sulfur content is removed (General Electric Co., Valley Forge PA).

- Battelle process leaches the coal with an alkali agent to remove approximately 95% of the pyritic and 25 to 50% of the organic sulfur content (Battelle Laboratories, Columbus OH).

- JPL process removes 95% of the pyritic and up to 70% of the organic sulfur content by chlorinolysis of the coal in an organic solvent (Jet Propulsion Laboratory, Pasadena CA).

- IGT process uses oxidative pretreatment of the coal followed by hydrodesulfurization at 800°C (1472°F) to remove 95% of the pyritic and up to 85% of the organic sulfur content (Institute of Gas Technology, Chicago IL).

- KVB process oxidizes the sulfur in a nitrous oxide atmosphere. Sulfates are washed from the coal. The process removes 95% of the pyritic and up to 40% of the organic sulfur content (KVB, Inc., Tustin CA).

- ARCO process uses a two-stage chemical oxidation procedure to remove 95% of the pyritic sulfur content and some organic sulfur from processed coal (Atlantic Richfield Co., Harvey IL).

The USEPA Industrial Environmental Research laboratory at Research Triangle Park NC has ongoing programs to identify and assess the environmental effects of coal cleaning technologies. Major project activities include:

- The development of a technology overview that describes all of the current coal cleaning processes and their pollution control problems

- The design and implementation of an environmental test program to obtain improved data on pollutants from commercial coal cleaning plants

- Trade-off studies that compare the cost effectiveness of coal cleaning and other SO_2 emission control strategies

- Studies to determine the relative environmental impacts of coal cleaning and flue gas desulfurization (FGD).

In addition to the contract research and development program Research Triangle Park, USEPA conducts cooperative projects with the Bureau of Mines the US Geological Survey, the US Department of Energy, and the Electric Power Research Institute.

1.3.3.3. Coal Transportation

Coal slurry pipelines may receive more favorable consideration by industry in the future planning of coal transportation systems (Chironis

1978). Six coal slurry pipelines are now planned or under construction (Figure 39). The longest and possibly largest pipeline would transport 19 to 34.5 million MT (21 to 38 T) per year over 2,030 km (1,260 mi) from the Powder River Basin, Montana, to Houston, Texas (Szabo 1978). Data are summarized in Table 13 that describe the coal slurry pipelines that are proposed or under construction.

Pneumatic pipelines for coal transportation also may receive closer scrutiny in future. One pipeline has been operated successfully in Colorado over a distance of 102 m (4,000 ft). A second pneumatic pipeline has been proposed to transport 5,440 MT (6,000 T) of coal per day from a mine near Carbondale, Colorado, to a railroad spur located 34 km (21 mi) away.

A pneumatic pipeline system includes a coal preparation plant, a pump to pressurize the pipeline, storage silos for the feed coal, and a cyclone, baghouse, and storage bins at the delivery end. Granulated coal from the preparation plant is loaded from bins into the pipeline. The pump maintains a load-end pipeline pressure of 10 atm at a mass flow of 1 part coal to 10 parts air. The pipe line telescopes to larger diameters downstream to accommodate the decreased density (increased volume) of the flowing mass. Coal is recovered at the delivery end by cyclones that capture particles larger than 5 microns (0.0002 in) at 98% efficiency. The remaining particles are removed in the baghouse (Szabo 1978). The captured coal fines may be stored in bins or silos for loading by other transportation modes.

1.3.4. Water Pollution Control

On 12 January 1979, USEPA promulgated regulations (40 CFR 434; 44 FR 9:2586-2592) that specify the standards of performance for new source coal mines and preparation plants based on the best available demonstrated control technology for wastewater discharge. These regulations mandate the use of treatment and control technologies to minimize the potential environmental effects of mine drainage and process waters discharged to the environment. Effluent limitations were expressed as concentrations in the waste stream rather than total pollutant load per unit of product, because no correlation was found between the volume of water treated and discharged and the tonnage of coal mined or processed.

USEPA expects that advances in plant design will result in little or no discharge of cleaning plant process water to the environment, although at this time there is no requirement to recycle preparation plant process water. The use of techniques which reduce the influx of water to underground mines (Section 3.1) may in future reduce the volume of mine wastewater requiring treatment before discharge.

1.3.5. Environmental Impact

Implementation of Federal and State effluent limitations for point source discharges has resulted in noticeable improvement of the quality of some surface waters previously degraded by coal mining activity. Continued

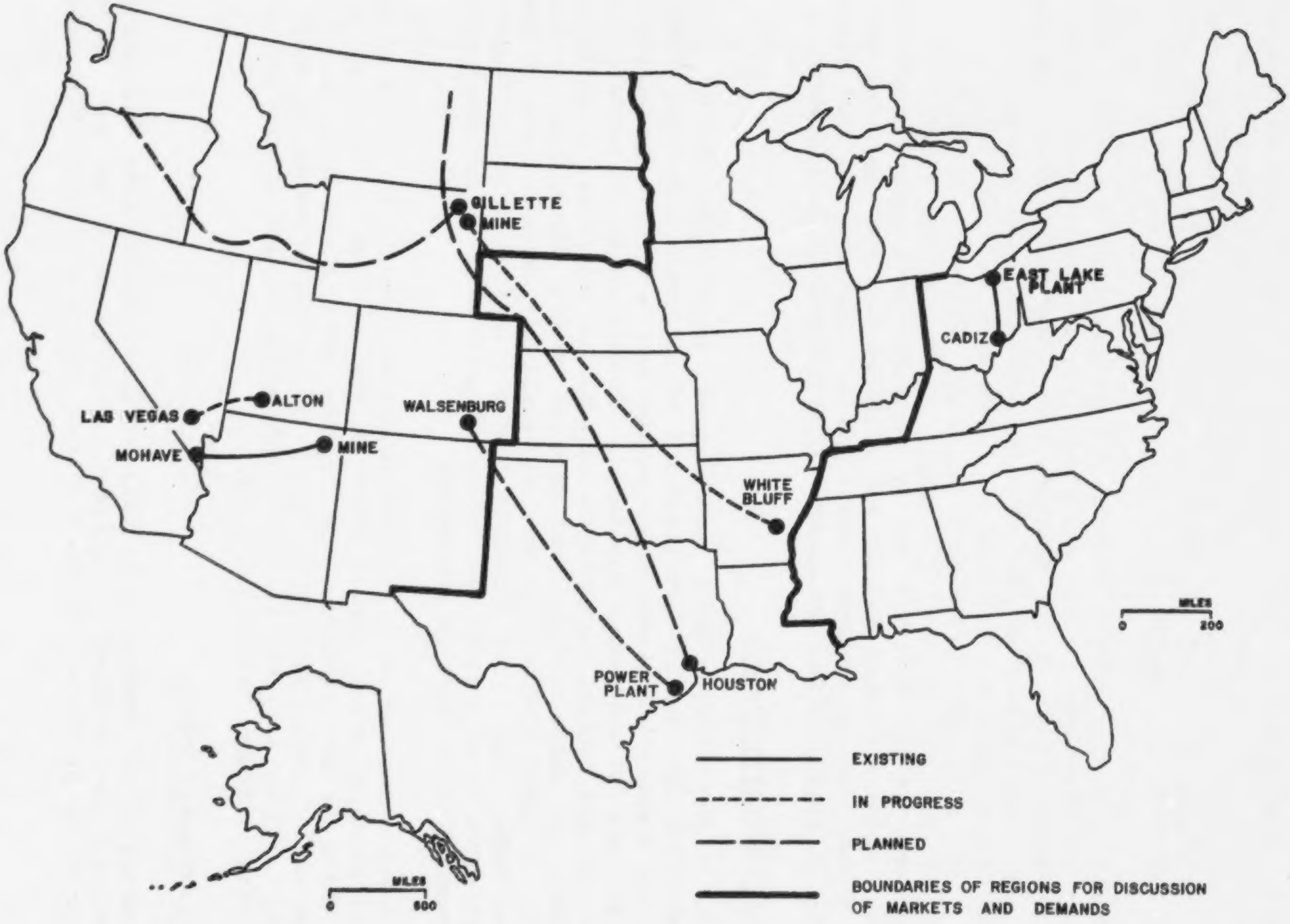

GILLETTE
MINE
LAS VEGAS
ALTON
MOHAVE
MINE
WALSENBURG
WHITE BLUFF
EAST LAKE PLANT
CADIZ
POWER PLANT
HOUSTON
MILES
0
200
MILES
0
600
EXISTING
IN PROGRESS
PLANNED
BOUNDARIES OF REGIONS FOR DISCUSSION OF MARKETS AND DEMANDS

Figure 39. Status of coal slurry pipelines in the United States.

Source: Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.

Table 13. Coal slurry pipelines that are proposed or under construction in the US.

System	Origin	Destination	Annual throughput million MT (million T)	Length Km (mi)	Pipeline diameter cm (in)
Energy Transportation Systems, Inc.	Gillette WY	White Bluff AR	22.7 (25)	1,667 (1,036)	96.5 (38)
Gulf Interstate Northwest	Gillette WY	Columbia River Valley, OR	9 (10)	1,770 (1,100)	51 to 61 (20 to 24)
Houston Natural Gas	Walsenburg CO	near Houston TX	13.6 (15)	1,784 (1,109)	20 to 71 (8 to 28)
Nevada Power	Alton UT	Las Vegas NV	9 (10)	290 (180)	61 (24)
Wytex	Powder River Basin MT	Houston TX	19 to 34.5 (21 to 38)	2,510 (1,560)	20 to 71 (8 to 28)

Source: Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081m 141 p.

improvement in the environmental quality of areas disturbed by mining is expected as pollution control technologies improve. Implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) is expected to reduce further the potentially adverse environmental effects associated with coal mining by mandating site-specific environmental studies prior to development of underground mines which disturb more than 0.8 ha (1.0 ac) of surface area. These legislative and administrative activities coincide with a projected significant increase in coal production which, in the absence of effective mandates for control, could significantly degrade the environment.

1.4 MARKETS AND DEMANDS

1.4.1. Markets

Approximately 95% of the coal produced in the US is committed to sales contracts or other delivery agreements in advance of production. This figure includes the production from mines wholly owned by steel producers, utilities, and other high-volume coal consumers. The remaining 5% is sold on the open market, known in the industry as the spot market. Most coal that is sold on the spot market is mined in the east, generally by small mining operations that do not produce the high volume of coal necessary to win long-term sales agreements.

Data are compiled by the US Department of Energy (USDOE) that show the trends in coal consumption among four major groups of users (USEIA 1979).

- Electric utilities -- All privately owned companies and public agencies engaged in the production or distribution of electric power

- Cokeplants -- All plants where bituminous coal is carbonized for the manufacture of coke in slot or beehive ovens

- All other industrial categories -- All industrial consumers of bituminous coal and lignite other than electric utilities and coke plants

- Retail sales -- Retail sales of coal for commercial or residential heating

Electric utilities increased their consumption of US coal by 79 million MT (86.9 million T) between 1974 and 1978 (Table 14). Consumption of coal for coke ovens and space heating decreased steadily during the same period. Other industrial categories experienced a net decline in coal use following 1974, although industrial coal consumption has risen steadily since, except during 1976 (Table 15). The use of coal for space heating decreased by over 4 million MT (4.4 million T) between 1974 and 1978. Figure 40 illustrates these trends in coal use.

Table 14. Domestic market consumption of bituminous coal and lignite produced in the US during 1974 through 1978 (millions of MT).

Consumer Use	Calendar Year 1974	1975	1976	1977	1978
Electric Utilities	357	399	421	445	436
Coke Plants	84.7	84.1	84.3	77.2	64.7
Other industrial categories	57.5	48.6	48.3	54.2	55.3
Retail Sales	6.17	4.58	3.76	2.81	1.90
Total[1]	505	536	557	580	558

[1] Data may not add to totals shown because of independent rounding.

Source: US Energy Information Administration. 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, Washington DC, DOE/EIA-0125/4Q78, 85p.

Table 15. Market consumption by percentage of bituminous coal and lignite produced in the US during 1974 through 1978.

Consumer Use	Calendar Year				
	1974	1975	1976	1977	1978
Electric Utilities	70.6	74.4	75.5	76.8	78.2
Coke Plants	16.8	15.7	15.1	13.3	11.6
Other industrial categories	11.4	9.1	8.7	9.3	9.9
Retail Sales	1.2	0.9	0.7	0.5	0.3
Total[1]	100.0	100.0	100.0	100.0	100.0

Source: US Energy Information Administration. 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, Washington DC, DOE/EIA-0125/4Q78, 85 p.

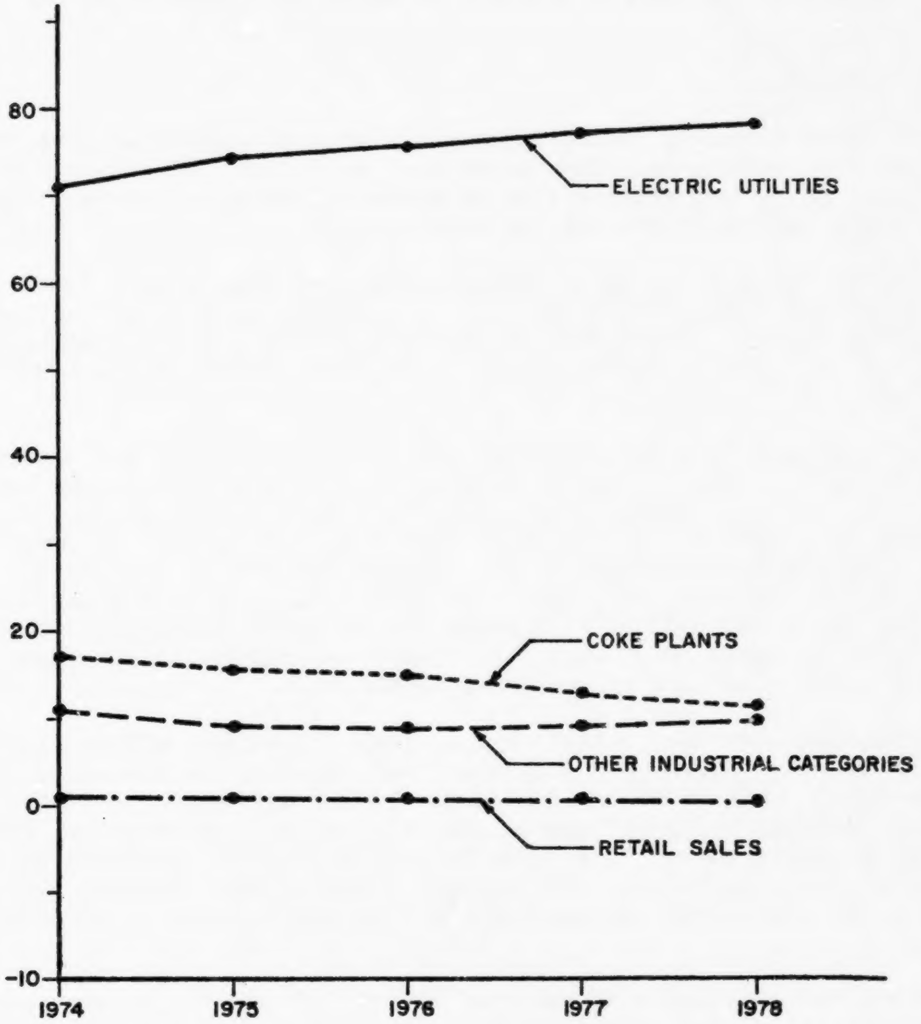


Figure 40. Trends in the proportionate consumption of annual coal production for major consumer categories, 1974 through 1978.

Source: US Energy Information Administration. 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, Washington DC, DOE/EIA-0125/4Q78, 85 p.

Domestic bituminous coal production increased steadily from 1974 through 1977. Anthracite production showed a net decrease of 609 thousand MT (670 thousand T) during the same period (Table 16). A series of work stoppages curtailed coal mining activities for the first three months of 1978, depressing the year's production below the level achieved during 1975.

1.4.2. Demands

The USDOE developed regional forecasts of coal production through 1990 based on low, medium, and high production scenarios that account for the anticipated prices and capabilities of competing energy resources, transportation costs, and environmental regulations.

The low and high scenarios reflect lower and upper bounds beyond which coal production reasonably would not be expected to decrease or increase during that period. The medium scenario represents a more probable set of production statistics (USDOE 1978b). Regional boundaries are shown in Figure 39.

The regional forecasts for coal production by surface and underground mining methods indicate a marked shift of production capacity to the West (Table 17). Large western surface mines are expected to provide the coal necessary to close the gap between current production and projected tonnages. The forecasted changes in underground coal mining capacity are relatively small. Eastern coal production from underground mines may increase by 53 million MT (58 million T) between 1985 and 1990 (Table 18). The relative share in total production by western underground coal mines would decrease as total production increased (Table 19).

These forecasts were revised by the USDOE to reflect refinements in the assumptions on regulatory constraints and pricing of competing energy sources (USDOE 1979). The new forecasts are not appreciably different from the old, although the band between the high and low scenarios of 1995 was narrowed by approximately 91 million MT (100 million T). Regional shifts of forecasted coal production did occur. These data, however, were not reported for individual mining methods and therefore are not discussed here.

Production shortfalls in the coal mining industry may be attributed to the general, historical trend of decreasing productivity caused by safety and environmental regulations (Hittman Associates, Inc. 1976). Other causes of the shortfall may include the undercapitalization of the industry in general and the shortage of trained manpower and mining machines to construct and operate a significant number of new mines.

The quality of coal mined by underground methods varies from high-value coking coals to low-value fuel coals. To satisfy air pollution standards for electric generating facilities, coals with naturally low sulfur contents and coals that are amenable to significant reduction of sulfur content by

Table 16. US coal production during 1973 through 1978 (thousands of MT).

Resource	Calendar Year					
	1973[a]	1974[a]	1975[a]	1976[a]	1977[a]	1978[b]
Anthracite	6,209	6,015	5,639	5,662	5,600	c
Bituminous, Subbituminous and Lignite	537,944	548,551	589,489	616,986	623,000	588,500
Total	544,153	554,566	595,128	622,648	628,000	588,500

Sources: a. US Bureau of Mines. 1978. Mineral commodity summaries. US Department of the Interior, Washington DC, 200 p.

b. US Energy Information Administration. 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, Washington DC, DOE/EIA-0125/4Q78, 85 p.

c. Not available

Table 17. Regional forecasts of US coal production from surface and underground mines (millions of MT).

Region	1985			1990		
	Low	Medium	High	Low	Medium	High
East	388	400	413	360	405	435
Midwest	227	248	256	306	366	401
West	285	367	411	347	612	851
Total	900	1,015	1,080	1,013	1,383	1,687

Source: US Office of Surface Mining Reclamation and Enforcement. 1979. Permanent regulatory program implementing Section 501(b) of the Surface Mining Control and Reclamation Act of 1977: final environmental statement. US Department of the Interior, Washington DC, OSM-EIS-1, variously paged.

Table 18. Regional forecasts of US coal production by underground mining methods (millions of MT).

Region	1985			1990		
	Low	Medium	High	Low	Medium	High
East	271	280	290	273	314	343
Midwest	112	132	141	205	249	261
West	25	26	26	26	34	33
Total	408	438	457	504	597	637

Source: US Office of Surface Mining Reclamation and Enforcement. 1979. Permanent regulatory program implementing Section 501(b) of the Surface Mining Control and Reclamation Act of 1977: final environmental statement. US Department of the Interior, Washington DC, OSM-EIS-1, variously paged.

Table 19. Percentage of forecasted US production attributable to underground minable coal, based on Tables 17 and 18.

Region	1985			1990		
	Low	Medium	High	Low	Medium	High
East	70	70	70	76	78	79
Midwest	45	53	55	67	68	65
West	9	7	6	7	6	4
Total	44	43	42	50	43	38

Source: US Office of Surface Mining Reclamation and Enforcement. 1979. Permanent regulatory program implementing Section 501(b) of the Surface Mining Control and Reclamation Act of 1977: final environmental statement. US Department of the Interior, Washington DC, OSM-EIS-1, variously paged.

cleaning will be in higher demand than coals of comparatively lower quality. The demand for metallurgical grade coals generally has decreased since 1973, reflecting the general decrease in US steel production (USBOM 1978).

Desulfurization of coal by physical or chemical cleaning processes currently is not practiced at commercial scale, although demonstration plants and pilot facilities currently are in use. The projected demand for steam grade coal, therefore, will concentrate initially on coals with comparatively lower sulfur contents. As the feasibility of coal desulfurization is enhanced by implementation of improved, demonstrated technology, coal consumers may elect to use local, cleanable, high sulfur coals instead of low sulfur coals requiring transportation over greater distances. The factors which constrain such choices include the costs of transportation, coal processing, and environmental regulation, all of which may vary significantly at the regional level.

1.5. SIGNIFICANT ENVIRONMENTAL PROBLEMS

The implementation of Congressionally-mandated pollution control strategies for the coal mining industry should reduce significantly the magnitude of many environmental impacts that historically are associated with underground coal mining and coal preparation. The impact of land subsidence from underground mining, however, is the subject of continuing investigation as a compromise is sought between maximum recovery of the coal resource and minimum damage to the environment. The following discussion highlights the major environmental problems of coal cleaning and underground coal mining operations. Section 2 describes these and other environmental problems in greater detail.

1.5.1. Location

Underground mining produces land subsidence where insufficient coal or other material is left in place to support the roof. New underground mines, therefore, are sited away from developed areas whenever possible. Longwall and shortwall systems especially result in subsidence and therefore are utilized only in locations where some subsidence is tolerable.

Coal cleaning operations and associated areas require open space. Typically they are designed to maximize the use of the affected area and to minimize the need for extensive stormwater and wastewater control systems. Coal cleaning operations generally are located proximate to the mines which they serve, thereby limiting the distance which coal must travel before extraneous material is removed and it is salable. If a large proportion of the ROM coal is unsalable, the cost of transport, and hence the distance between the mine and the preparation plant, may be critical to operating the mine profitably.

1.5.2. Raw Materials and Energy

The electricity that is used to operate underground coal mines and cleaning plants generally is purchased from a local utility company, unless it can be generated more cheaply at the site of operation. A generating station constructed to service new mining operations represents potential stress on the environment which must be addressed in terms of both its primary and secondary effects before the full effects of mine development or plant construction can be assessed properly.

The raw material for at least one phase of many coal cleaning operations is the coal refuse that is processed through advanced stages of sizing and separation. Refuse from the primary sizing and crushing of ROM coal may contain considerable combustible material that is recoverable by advanced cleaning techniques. Permanent burial or other disposal of this potentially recyclable refuse may represent a long-term commitment of resources for the short-term gain of salable coal.

1.5.3. Process

The potentially significant environmental problems associated with underground coal mining include:

- Disruption of natural earth materials by creating voids that promote subsidence of mined areas
- Dewatering of aquifers by disruption or removal of coal seams and confining strata or water-bearing strata
- Fugitive dust from surface operations and mine ventilation
- Solid wastes that contain pollutants which can cause long-term, adverse effects on the environment

Coal cleaning operations also generate solid wastes, effluents, and fugitive dust, as well as potentially noxious emissions from thermal dryers.

Additional problems associated with coal mining and cleaning processes include the usurpation of open space; the dedication of transportation, electricity, and other regional resource to industrial use; and the potential secondary effects of work force fluctuations and additional demands for municipal services on communities near the new operations.

Numerous chemical elements and compounds occur in higher concentrations in coal seams and associated strata than elsewhere in the earth's crust. Although many of these chemical species currently are not recognized as pollutants with known toxic effects, the USEPA has ongoing research to establish the threshold concentrations of minor chemical constituents in coal that pose hazards to human health or the ecological balance (Ewing and others 1978).

1.5.4. Pollution Control

The pollution control devices that may be used to achieve the Federally mandated effluent and emission limitations (Section 1.7.) produce solid wastes that may require preparation (e.g. neutralization or dewatering) before disposal. These solids are described more thoroughly in Section 3.2.

1.6 POLLUTION CONTROL REGULATIONS

Federal regulations have been promulgated that control the discharge of process waste pollutants to the environment. The USEPA administers regulatory programs that limit the concentrations of pollutants to be discharged in emissions (Section 1.6.1.) and effluents (Section 1.6.2.). Solid wastes from coal mining and cleaning operations currently are regulated by USEPA if they contain hazardous or toxic materials. The regulatory programs that are administered by the US Office of Surface Mining Reclamation and Enforcement (USOSM) under the US Department of the Interior (USDOI) explicitly address the disposal of solid wastes from coal mining and cleaning operations (Section 1.6.3.).

1.6.1. Air Pollution Performance Standards

Underground coal mining and coal cleaning operations are affected by a four-point regulatory program for the control of atmospheric emissions. The basic elements of the program include:

- National Ambient Air Quality Standards (NAAQS's) that establish the maximum concentrations of pollutants legally allowable Nationwide

- State Implementation Plans (SIP's) that specify the methods by which the States will achieve compliance with the NAAQS's

- New Source Performance Standards (NSPS's) that require coal cleaning facilities with thermal dryers to utilize the Best Available Control Technology (BACT) to meet specific emission limitations

- Prevention of Significant Deterioration (PSD) permits that require the approval of the regulatory authority prior to the construction of an emitting facility in an air quality classified area.

The full program implements the Clean Air Act (CAA; 42 USC 7401-7642) as amended during 1974 (PL 93-319, 88 Stat. 246) and 1977 (PL 95-95, 91 Stat. 685; and PL 95-190, 91 Stat. 1401-02; Quarles 1979).

The NAAQS's are the cornerstone for preserving and enhancing the Nation's ambient air quality. The NAAQS's include primary and secondary standards (Table 20). Primary standards specify the maximum permissible ambient pollutant concentrations to prevent adverse effects on human health. Secondary standards specify the maximum concentrations to prevent adverse effects on sensitive environmental resources.

To achieve the levels of environmental protection specified by the NAAQS's, Congress directed the several States to formulate plans to achieve the goals of the CAA within a specific timetable. The Nation was divided into 247 Air Quality Control Regions (AQCR's) based on available air quality data. Ambient concentrations of pollutants were estimated for each AQCR from the results of air sampling programs. These estimates were compared with the NAAQS's to determine the scope of regulatory activities in each AQCR that would be necessary to achieve the National goal of clean air.

Each State developed plans (SIP's) to regulate the emission of air pollutants on a regional basis. SIP's establish procedures and criteria to control the level of emissions from existing and proposed sources.

The USEPA published New Source Performance Standards (NSPS's) for coal cleaning operations with thermal dryers on 15 January 1976 (40 CFR 60-250; 41 FR 10: 2232). These regulations require that the State be consulted at critical junctures of plant operation, including:

- Pre-construction planning -- The State regulatory authority should be informed of construction plans and cleaning facility characteristics before construction commences.

- Pre-startup operations -- The State again should be notified before the cleaning facility begins operation.

- Routine operations -- The plant operator must submit air quality monitoring data to the State at specific intervals throughout the operation of the cleaning facility.

The current NSPS's for coal cleaning operations that process more than 181 MT (200 T) of coal per day specify the limits for opacity and particulate emissions permissible from thermal dryers, pneumatic coal cleaning equipment, and coal handling and storage equipment (Table 21). These proposed regulations currently are in effect, although they are not yet corroborated by final NSPS's for coal preparation plants and handling facilities.

The CAA also mandated a regulatory program to require preconstruction approval of industrial facilities that potentially would produce significant air emissions in areas that have specific air quality problems or goals. These requirements for the prevention of significant deterioration (PSD) of local air quality include two major components (Quarles 1979).

Table 20. Federal ambient air quality standards.

EMISSION	STANDARD[1]	
	Primary	Secondary
Sulfur dioxide	80 μg/m^3 annual arithmetic mean	1,300 μg/m^3 maximum 3-hr concentration
	365 μg/m^3 maximum 24-hr concentration	
Particulate matter	75 μg/m^3 annual geometric mean	150 μg/m^3 maximum 24-hr concentration
	260 μg/m^3 maximum 24-hr concentration	60 μg/m^3 annual geometric mean as a guide in assessing implementation plans
Nitrogen dioxide[2]	100 μg/m^3 annual arithmetic mean	100 μg/m^3 annual arithmetic mean
Ozone	235 μg/m^3 (0.12 ppm) maximum 1-hr concentration	235 μg/m^3 (0.12 ppm) maximum 1-hr concentration
Carbon monoxide	10 mg/m^3 (9 ppm) maximum 8-hr concentration	10 mg/m^3 (9 ppm) maximum 8-hr concentration
	40 mg/m^3 (35 ppm) maximum 1-hr concentration	40 mg/m^3 (35 ppm) maximum 1-hr concentration

[1] For any standard other than annual, the maximum allowable concentration may be exceeded for the prescribed period once each year.

[2] The Clean Air Act Amendments of 1977 (PL 95-95) require the USEPA Administrator to promulgate a national primary ambient air quality standard for NO_2 concentration over a period of not more than 3 hr unless, based on the criteria issued under Section 108(c), he finds that there is no significant evidence that such a standard for such a period is requisite to protect public health.

Source: 40 CFR 50

Table 21. Summary of new source performance standards for bituminous coal preparation plants and handling facilities capable of processing more than 181 MT (200 T) of coal per day.

Equipment	Opacity Limitation (%)	Particulate Concentration Standard (g/dscm)	Particulate Concentration Standard (gr/dscf)
Thermal Dryers	20	0.070	0.031
Pneumatic Coal Cleaning Equipment	10	0.040	0.018
Coal Handling and Storage Equipment	20	-	-

Source: 40 CFR 60.250; 41 FR 10:2232, 15 January 1976.

Table 22. Nondeterioration increments: maximum allowable increase by PSD class of the AQCR.

Pollutant*	Class I ($\mu g/m^3$)	Class II ($\mu g/m^3$)	Class III ($\mu g/m^3$)
Particulate matter:			
Annual geometric mean	5	19	37
24-hour maximum	10	37	75
Sulfur dioxide:			
Annual arithmetic mean	1	20	40
24-hour maximum	5**	91	182
3-hour maximum	25**	512	700

*Other pollutants for which PSD regulations will be promulgated are to include hydrocarbons, carbon monoxide, photochemical oxidants, and nitrogen oxides.

**A variance may be allowed to exceed each of these increments on 18 days per year, subject to limiting 24-hour increments of 26 $\mu g/m^3$ for low terrain and 62 $\mu g/m^3$ for high terrain and 3-hour increments of 130 $\mu g/m^3$ for low terrain and 221 $\mu g/m^3$ for high terrain. To obtain such a variance both State and Federal approval is required.

Source: Public Law 95-95. 1977. Clean Air Act Amendments of 1977, Part C, Subpart 1, Section 163.

- Area classification system -- All areas of the Nation are classified on the basis of regional air quality goals and the existing ambient air quality. The purpose of the classification system is to permit local industrial activity without the degradation of local air quality to the point where compliance with ambient air quality standards is minimal or non-existent. The States may designate areas where pristine air quality is to be protected by preventing excessive emissions of regulated pollutants. Three classes of air quality areas have been established:

  -- Class I areas have pristine air quality and therefore are subject to stringent restrictions or emissions.

  -- Class II areas have air quality that has been affected by moderate industrial activity. All areas of the country originally were designated by USEPA as Class II. States were authorized to redesignate these areas as Class I or Class II, based on established procedures.

  -- Class III areas have air quality that has been affected by major industrial activity.

- Permissible increments of selected emissions -- Numerical limitations specify permissible increases of pollutant concentrations above existing concentrations.

Each air quality class is protected from significant deterioration by a system of allowable increments of air emissions that reflect the combined air quality effects of new industrial growth in the classified area (Table 22). To protect areas of pristine air quality, Class I increments are more restrictive than those for Class II or Class III. For example, if the existing concentration of particulates in a Class I area is 30 $\mu g/m^3$, new industrial activity would be permitted to contribute no more than 5 $\mu g/m^3$ additional particulates annually to the local atmosphere. The new ambient concentration of particulates for the area would be increased to no more than 35 $\mu g/m^3$. For a Class II area with identical baseline conditions, the increment for particulates is 19 $\mu g/m^3$. The allowable ambient concentrations of particulates from all industrial activity in the area thus would be limited to 49 $\mu g/m^3$. In Class III areas, the increment for particulates is 37 $\mu g/m^3$. Industrial expansion would be permitted so long as ambient particulate concentrations did not exceed the limit of 67 $\mu g/m^3$.

Other provisions under PSD include the application of BACT to industrial facilities on a case by case basis. The use of BACT for a coal cleaning facility can be mandated by the regulatory authority through a set of conditions attached to an individual PSD permit. The permit conditions also may reflect the results of any public hearing on the permit application, and may be modified to account for changes in local air quality that are detected during the applicant's air quality monitoring program that is required for post-construction activities. Coal cleaning facilities that emit less than 45 MT (50 T) of pollutants per year may be exempt from compliance with PSD increments and requirements to install BACT.

1.6.2. Water Pollution Performance Standards

On 12 January 1979, USEPA published final regulations that specify the new source performance standards and effluent limitations applicable to the coal mining point source category effective 12 February 1979 (40 CFR 434; 44 FR 9:2586-2592; Table 23). New source NPDES permits for the coal mining industry differ significantly from the existing source NPDES permits which USEPA began to administer several years ago. First, the new source limitations are more restrictive than the existing source limitations for total iron. Second, each new source permit must be approved prior to the construction of the proposed new source. Third, new source NPDES permit actions may be subject to comprehensive environmental review by USEPA in accordance with NEPA, as well as other applicable environmentally protective laws and regulations. Hence the new source program offers significantly enhanced opportunity, as compared with the existing source program, for: (1) public and interagency input to the Federal NPDES permit review process; (2) effective environmental review and consideration of alternatives; and (3) implementation of environmentally protective permit conditions on mine planning, operation, and decommissioning.

An underground coal mine or coal cleaning operation is designated as a new source on the basis of timing and other considerations. Two kinds of facilities are designated new sources automatically:

- Coal preparation plants that are constructed outside the permit areas of neighboring mines on or after 12 February 1979

- Underground mines that are assigned identifying numbers by the Mining Safety and Health Administration (MSHA) on or after 12 February 1979.

Underground coal mines that operate under existing source permits may be designated as new sources if one or more of the following conditions apply:

-- Mining is begun in a new coal seam.

-- Effluent is discharged to a new drainage basin.

-- Extensive new surface disruption occurs.

-- Construction of a new shaft, slope, or drift entryway is begun.

Table 23. Nationwide performance standards for wastewater discharged after application of the best available demonstrated control technology by new sources in the coal mining point source category. The limitations are not applicable to excess water discharged as a result of precipitation of snow melt in excess of the 10-year, 24-hour precipitation event (40 CFR 434; 44 FR 9:2586-2592, 12 January 1979). Units are milligrams per liter (mg/l) except as otherwise indicated.

			BITUMINOUS, LIGNITE, AND ANTHRACITE MINING			
	Coal Preparation Plants And Associated Areas		Acid or Ferruginous Mine Drainage[1]		Alkaline Mine Drainage[1]	
Parameter	1-day Maximum	Average of 30 consecutive daily values	1-day Maximum	Average of 30 consecutive daily values	1-day Maximum	Average of 30 consecutive daily values
Total suspended solids	70.0	35.0	70.0[2]	35.0[2]	70.0[2]	35.0[2]
Total iron	6.0	3.0	6.0	3.0	6.0	3.0
Total manganese	4.0	2.0	4.0	2.0		
pH (pH units)	range 6.0-9.0		range 6.0-9.0		range 6.0-9.0	

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[1] Drainage which is not from an active mining area (for example, a regraded area) is not required to meet the stated limitations unless it is mixed with untreated mine drainage that is subject to the limitations.

[2] Total suspended solids limitations do not apply in Colorado, Montana, North Dakota, South Dakota, and Wyoming. In these states, limitations for total suspended solids are determined on a case by case basis.

-- Additional land or mineral rights are acquired.

-- Significant new capital is invested in the operation

The Regional Administrator may identify other characteristics of underground mines that should be considered for redesignating an existing source mine as a new source. Underground coal mines will be designated as new sources case by case, primarily on the basis of information supplied by the NPDES permit applicants.

The new source NPDES permit program may be administered by the USEPA directly or by the States under a program approved by the USEPA. Of the following States in which USEPA administers the NPDES permit program directly, Arizona, Florida, Louisiana, New Jersey, and South Dakota lack underground minable coal reserves.

State	USEPA Region	State	USEPA Region
		New Jersey	II
Alaska	X	New Mexico	VI
Arizona	IX	Oklahoma	VI
Arkansas	VI	Texas	VI
Florida	IV	Utah	VIII
Idaho	X	West Virginia	III
Kentucky	IV	South Dakota	VIII
Louisiana	VI		

The USEPA new source effluent limitations apply only to wastewater discharged from active mining areas and preparation plants. They do not apply to runoff from land that has been regraded in accordance with a mining plan, so long as it is not mixed with mine discharge, or to discharge from abandoned mines. Areas undergoing reclamation are considered to be a separate subcategory from active mines and coal preparation plants. No limitations for the reclamation subcategory have been proposed by USEPA, and the final new source regulations do not address directly the long-term discharge of effluents from surface-disturbed areas following the completion of revegetation.

1.6.3. Underground Coal Mining Performance Standards

Underground coal mines and coal preparation plants that disturb more than 0.8 ha (2 ac) of surface area are regulated under programs mandated by the Surface Mining Control and Reclamation Act of 1977 (SMCRA; 30 USC 1201 *et seq*.). The Office of Surface Mining Reclamation and Enforcement (USOSM) was established under Title II of the SMCRA. The responsibilities of USOSM broadly include:

- The promulgation of performance standards for surface mines and the surface operations of underground mines and coal cleaning facilities

- Approving and monitoring State-administered programs to regulate the coal mining industry

- Administering various programs to repair the legacy of previous mining, and advancing the technology of coal mining and reclamation

Final regulations for the USOSM interim regulatory program were published on 13 December 1977 (43 FR 239:62639-62716). These regulations focus primarily on the prevention or mitigation of potentially adverse effects of coal mining on the hydrologic balance. Environmentally sensitive hydrologic resources are to be protected through the use of in-process and end-of-process controls to reduce or eliminate the discharge of pollutant loads to the hydrologic regime.

Final regulations that describe the USOSM permanent regulatory program were published on 13 March 1979 (30 CFR Chapter VII; 44 FR 50:15311-15463). Of the eleven new subchapters thus promulgated (two additional subchapters appear in the 13 December 1977 final regulations), two subchapters bear directly on the scope and extent of information necessary to support permit applications to operate underground coal mines and coal cleaning facilities:

- Subchapter G: Permits for surface coal mining operations

- Subchapter K: Permanent program environmental performance standards

Regulations which govern the design of sedimentation ponds and head-of-hollow fills, originally published on 13 December 1977, were revised and published as proposed regulations on 14 November 1978 (30 CFR Parts 715 and 717; 43 FR 220:52734-52757). These proposed regulations reflect a reconsideration of design criteria for these structures as mandated by the District Court of the District of Columbia (Mem. Op. filed 24 August 1978).

The USOSM responsibilities for regulating the coal mining industry are partly coincident with the USEPA mandate to regulate water and air pollution under the Clean Water Act, the Clean Air Act, and the Resource Conservation and Recovery Act of 1976 (RCRA; PL 94-580; 43 USC 6901 et seq.). Both agencies have the power either to grant permits directly or to oversee the granting of permits by the States. Both agencies are constrained to avoid duplicative effort--the USEPA under Section 101.(f) of the Clean Water Act, and the USOSM under Section 201.(c)(12) of the SMCRA.

1.6.3 Solid Waste Regulations

The Resource Conservation and Recovery Act (RCRA), P.L. 94-580, defines "solid waste" as including solid, liquid, semisolid, or contained gaseous materials. Regulations implementing Subtitle C of the Act (40 CFR Part 261) provide that a solid waste is a hazardous waste if it is, or contains, a hazardous waste listed in Subpart D of Part 261 or the waste exhibits any of the characteristics defined in Subpart C. These charcateristics include:

- Ignitability (flash point below 60° C (140° F)
- Corrosivity
- Reactivity
- Toxicity

Hazardous wastes are identified in 40 CFR 261 Subpart D. The hazardous substances identified at this time in Subpart D do not include the major solid wastes of the underground coal mining and coal preparation industry. However, this does not eliminate the possibility of other industry wastes having "hazardous" designations in the future. Wastes containing arsenic or cadmium, for example, may be considered hazardous if the toxic materials can be leached out at concentrations of 5 mg/l and 1 mg/l, respectively, using the EP (Extraction Procedure) toxicity test. The natur of the wastes to be generated by a particular new source coal mine or preparation plant will have to be carefully examined to determine the applicability of the hazardous waste designation.

All new facilities that will generate, transport, treat, store, or dispose of hazardous wastes must notify USEPA of this occurrence and obtain a USEPA identification number. Storage, treating, and disposal also require a permit.

The determination of whether wastes generated or handled are hazardous is the responsibility of the owner or operator of the generating or handling facility. The first step is to consult the promulgated list (CFR 261 Subpart D). If the waste is not listed, the second step is to determine whether the waste exhibits any of the hazardous characteristics of listed through analytical tests using procedures promulgated in the regulations of by applying known information about characteristics of the waste based on process or materials used.

If it is determined that a hazardous waste is generated, it should be quantified to determine applicability of the small generator exemption. This cutoff point is 2,200 pounds per month, but it drops to 2.2 pounds for any commercial product or manufacturing chemical intermediate having a generic name listed in Section 261.33. Containers that have been used to contain less than 21 quarts of Section 261.33 materials and less than 22 pounds of liners from such containers are also exempt. It is anticipated that this exemption may be available to many very small plants with, for example, only one machine tool and one small painting operation. However, as more information is obtained on the behavior of substances in a disposal environment, the terms of this exemption may be altered from time to time.

The hazardous waste management system is based on the use of a manifest prepared by the generator describing and quantifying the waste and designating a disposal, treatment, or storage facility permitted to receive the type waste described to which the waste is to be delivered. One alternate site may be designated. Copies of the manifest are turned over to the transporter and a copy must be signed and returned to the generator each time the waste changes hands. If the generator does not receive a copy from the designated receiving facility or alternate within 35 days, he must track the fate of the waste through the transporter and designated facility or facilities. If the manifest copy is not received in 45 days, the generator must file an Exception Report with USEPA or the cognizant state agency.

A copy of each manifest must be kept for three years or until a signed copy is received from the designated receiving facility. In turn, the signed copy must be kept for three years. The same retention period applies to each Annual Report required whether disposal, storage, or treatment occurs on-site or off-site.

The generator must also:

- package the waste in accordance with the applicable DOT regulations under 49 CFR Parts 173, 178, and 179;
- label each package in accordance with DOT regulations under 49 CFR 172;

- mark each package in accordance with the applicable DOT regulations under 49 CFR 172;
- mark each container of 110 gallons or less with the following DOT (49 CFR 172) notice:

> "Hazardous Waste - Federal Law Prohibits Improper Disposal. If found, contact the nearest police or public safety authority or the U.S. Environmental Protection Agency."

- supply appropriate placards for the transporting vehicle in accordance with DOT regulations under 49 CFR Part 172, Subpart F.

Waste in properly labelled and dated containers in compliance with the regulations may be stored on the generator's premises for up to 90 days without a storage permit. This is to permit time for accumulation for more economic pickup or to find an available permitted disposal facility.

Due to the cost and stringent design and operating requirements for permitted landfills, it is anticipated that most new generator plants will utilize off-site disposal facilities. However, any companies desiring to construct their own will be subject to 40 CFR Part 264.

Incineration is considered to be "treatment," and, as such, is also subject to Part 264 as are chemical, physical, and biological treatment of hazardous wastes, and a permit will be required. Totally enclosed treatment systems--such as in-pipe treatment of acid and alkaline solutions--are not subject to this part.

Although underground injection of wastes constitutes "disposal" as defined by RCRA, this activity will be regulated by the underground injection control (UIC) program adopted pursuant to the Safe Drinking Water Act (P.L. 93-523). The consolidated permit regulations (40 CFR Parts 122, 123, 124) govern the procedural aspects of this program; the technical considerations are contained in 40 CFR Part 146.

The disposal of innocuous solid wastes is subject to Subtitle D of RCRA and the implementing regulations (40 CFR Part 256). Recovery or disposal in an approved sanitary landfill will be required under a state program. Disposal in open dumps is prohibited. All existing state regulations which do not meet the requirements of Subtitle D are superseded.

2.0 IMPACT IDENTIFICATION

Underground coal mining and coal preparation generate wastes that have the potential to affect the environment adversely. This section focuses on the interfaces between these wastes and the environment by identifying (1) environmental resource elements which can affect or be adversely affected by coal preparation and underground mining operations; and (2) potential sources and characteristics of wastes, including emissions, effluents, and solids.

Underground coal mining is an extractive process and therefore produces environmental impacts which are similar nationwide. The severity of local effects of underground coal mining can vary significantly, based on the mining methods used and the presence of sensitive environmental resources. Coal preparation plants nationwide have grossly similar process operations, but generate wastes with chemical characteristics that vary regionally or locally with coal seam and overburden composition.

The key site characteristics that influence the magnitude and significance of environmental impacts include topography, geology (depth of overburden to coal seam, and the thickness and composition of the coal seam), soil composition, land use, hydrology, climate, and the presence of unique or sensitive natural features. The identification of environmental resources located in the proposed permit area and adjacent areas is a fundamental step in assessing the environmental effects of proposed coal cleaning and underground coal mining operations. The adjacent areas include those natural and human resources contiguous to or sufficiently near the proposed permit area that may be affected by the underground coal mining or coal cleaning operations conducted within the proposed permit area. The appropriate officials should be consulted to delineate the adjacent areas for assessment that are relevant to each proposed permit area.

Environmental resources that are especially sensitive to coal mining activities may require special consideration during the baseline inventory and environmental planning processes. Specific guidance on the presence, location, extent, or particular sensitivities of individual resource elements may be available from the Regional Administrator or from other Federal or State agencies. The sensitive resources described below are recognized as sensitive by the USEPA (40 CFR 434; 44 FR 9:2586-2592). Section 6 of these guidelines lists environmentally protective Federal legislation, regulations, and Executive Orders.

- Cultural Resources
    - Archaeological sites
    - Historical sites
    - Community integrity and quality
    - Acoustic environment
    - Recreational land uses
    - Wild and scenic rivers

- Ecological Resources
  - -- Sensitive ecosystems
  - -- Habitats of endangered species
  - -- Wetlands
  - -- National natural landmarks

- Geoenvironmental Resources
  - -- Prime agricultural lands
  - -- High sulfur coal seams
  - -- Toxic overburden
  - -- Alluvial valley floors
  - -- Steep slopes (greater than 25%)

- Water Resources
  - -- National Resource Waters
  - -- Saturated zone
  - -- Surface water
  - -- Groundwater

The following discussion presents the minimum site- and process-related data requirements for identification of the effects of proposed underground coal mines and coal cleaning facilities. The inventory checklists presented in the section are organized on the basis of impacted resources (air, water, and land) and impacting activities (treatment and disposal of wastes, mining and cleaning methods, and coal transportation). The permit applicant should consult with the appropriate USEPA or State official to determine the format for presenting environmental and process-related information to support each new source NPDES permit application.

The level of detail of the inventoried data should be sufficient to allow a determination of the critical issues that may be associated with a permit application. Some of these issues (such as existing air and water quality) may require more attention in some regions than in others. Certain issues (such as control or prediction of subsidence) may be of more or less, concern based on the mining methods proposed in the permit applcation. Coordination with the USEPA is recommended early in the mine planning and environmental inventory process to insure that key issues will be addressed adequately.

2.1. PROCESS WASTES

Process wastes include the emissions, effluents, and solids generated by mining and cleaning operations and associated treatment systems. To address adequately the impacts of coal mining and preparation wastes, the sources, quantities, and characteristics of those wastes should be identified to the extent possible. The following discussion generally describes the wastes, treatment residuals, and potential waste sources, from underground coal mines, coal cleaning facilities, and waste treatment processes. Checklists of environmental features and process-related items also are provided.

2.1.1. Mining and Preparation Waste

Waste streams generated by coal mining and preparation plant processes include emissions, effluents, and solids. Emissions are discussed first, followed by effluents and solids.

2.1.1.1. Air Emissions

The air quality in the vicinity of proposed coal mining and cleaning operations may be subject to protection under PSD considerations (Section 1.6.1.). The regulatory authority with responsibility for protecting local air quality may impose special monitoring requirements as a pre-condition to construction and operation of the proposed facility.

To develop a complete inventory of the affected air resources, local climatology and air quality should be described thoroughly. The relationship between atmospheric dispersion patterns and local topography should be discussed with the aid of models, if appropriate. The following resource elements should be addressed explicitly.

- Topography -- maps and text that describe:
  - -- Regional features that affect local meteorology.
  - -- Location of emission sources with respect to local topographic features
- Climate -- maximum, minimum, annual and monthly average data from applicable stations that describe:
  - -- rainfall
  - -- snowfall
  - -- temperature
  - -- wind rose (speed and direction)
  - -- severe weather events
- Air Quality -- data and text that describe atmospheric concentrations of:
  - -- particulates
  - -- NO_x
  - -- other parameters that may be required by the Regional Administrator

2.1.1.1.1. Sources of Air Emissions

Sources of air emissions from underground coal mining and coal cleaning operations include construction activities and process-related operations. Sources of air emissions during construction activities include unprotected spoils, haulroads, and vehicular exhausts.

Coal cleaning processes, coal transfer (Figure 41), and open air storage provide numerous sources for air emissions. The sources associated with coal transfer and cleaning are listed below (Nunenkamp 1976, Szabo 1978).

- Coal transfer activities
  - -- Raw coal transport to cleaning facility
  - -- Raw coal transfer to stacking hopper
  - -- Stacking
  - -- Raw coal storage
  - -- Raw coal transfer to cleaning operation
  - -- Coal fine transfer to gob pile

  - -- Cleaned coal transfer to storage and transportation facilities
  - -- Cleaned coal transport

- Coal cleaning activities:

  - -- Preliminary sizing (wet processes)
  - -- Dry crushing and sizing
  - -- Pneumatic separation
  - -- Thermal drying
  - -- Dryfeed and product transfer and loading

2.1.1.1.2. Quantities of Air Emissions

Each discrete coal transfer operation produces a quantity of particulates that may be quantifiable on the average. One study completed by the USEPA assumed an average particulate emission rate of 0.2 kg/MT (0.4 lb/T) for loading and unloading activities associated with all modes of transport. This rate is unadjusted for dust control measures that may be applicable to coal transfer methods. The uncontrolled particulate emission rate may be adjusted downward based on the moisture content of the transferred coal (Szabo 1978). Emissions from coal transport operations are discussed in Section 2.3.3.

Emission rates from coal cleaning operations depend on plant design and the types of control processes that are employed (Section 3). Products of combustion from the drying of coal and the coal-fired heat source include carbon monoxide, the oxides of sulfur and nitrogen, particulates, and hydrocarbons which generally are measured as those other than methane. The emission rates for oxides of nitrogen from dryers are comparable to those of coal-fired power plants. Sulfur oxide emissions from thermal dryers generally are an order of magnitude lower (Table 24). Carbon monoxide emissions from both sources individually are too low to control effectively (USEPA 1974b).

Particulates in general are the most abundant form of emissions from coal cleaning facilities, although other combustion products of coal also

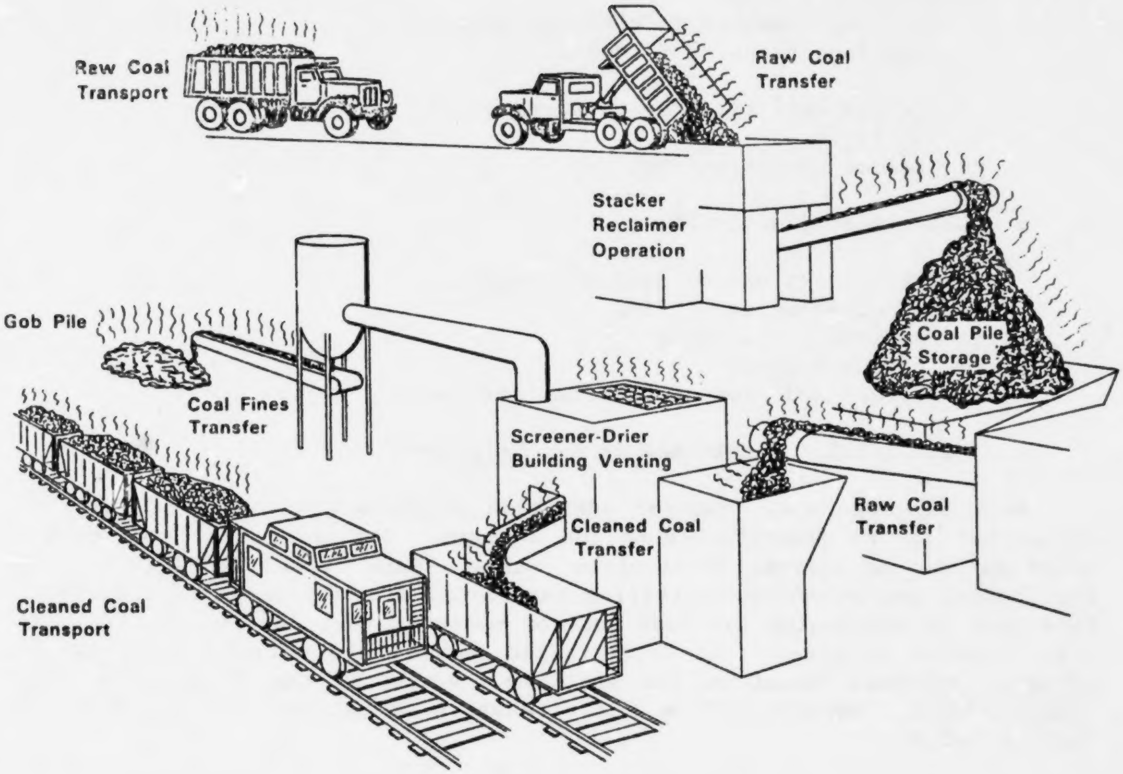

Raw Coal Transport
Raw Coal Transfer
Stacker Reclaimer Operation
Gob Pile
Coal Pile Storage
Coal Fines Transfer
Screener-Drier Building Venting
Raw Coal Transfer
Cleaned Coal Transfer
Cleaned Coal Transport

Figure 41. Emission sources associated with typical coal cleaning and transfer operations.

Source: Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Energy, Minerals, and Industry, Research Triangle Park NC, EPA-600/2-76-138, 727 p.

Table 24. Combustion product emissions from well controlled thermal dryers.

Pollutant	Concentration ppm	Emission Rate kg/million kg cal	Coal Fired Power Plant kg/million kg cal
NO_x	40-70	0.22 - 0.38	0.39
SO_x	0-11.2	0 - 0.05	0.67
Hydrocarbons (as methane)	20-100	0.04 - 0.19	-
CO	<50	<0.17	-

Source: US Environmental Protection Agency. 1974. Background information for standards of performance: coal preparation plants. Volume 1: proposed standards. US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park NC, EPA-450/2-74-021a, 40 p.

are produced during thermal drying (Table 25). Thermal dryers generally produce the bulk of particulate emissions from coal cleaning apparatus. The ultra-fine particles (<0.0075 cm) are entrained by combustion gases and carried from the dryers at rates that vary by dryer design (USEPA 1974b). Typical emission rates upstream from the dust control apparatus of selected dryers include (Nunenkamp 1976):

- Fluidized bed -- 10 kg/MT (20 lb/T)
- Flash -- 8 kg/MT (16 lb/T)
- Multilouvered -- 12.5 kg/MT (25 lb/T)

Particulate emissions from coal cleaning operations include:

- Coal dust
- Carbon or soot particles
- Metallic oxides and salts
- Acid droplets
- Silicates or other inorganic dusts

Thermal dryers generally emit trace elements as particulate matter. As an average, a well-controlled thermal dryer with a feed capacity of 450 MT (500 T) per hour discharges approximately 0.13 gr (2 grains) of arsenic per hour. Fluorine and selenium are known to occur in coal, although they are not detected in most thermal dryer emission streams (USEPA 1974b; Table 26).

The compositions and concentrations of organic gases emitted from thermal dryers are functions of dryer temperatures, feed rates, and coal characteristics. The kinds of polycyclic organic materials (POM's) that are emitted as gases by thermal dryers may be similar to those emitted by coal refuse fires (Table 27). Emission rates of hydrocarbons from coal cleaning facilities generally are considered to be too low for regulatory control (USEPA 1974b).

The extent of the environmental problems associated with particulate matter and aerosols depends on the size and composition of particles and the presence of air flows of sufficient velocity to spread pollutants from points of origin. Dust concentrations associated with the surface operations of underground coal mines and coal cleaning facilities may be exacerbated by movements of coal and machinery. Natural wind velocity, however, often may be adequate to lift particulate matter from unprotected surfaces without the additional impetus provided by the operation of machinery and the loading and transport of coal (Table 28). Other natural factors that affect the suspension and transport of dust include season, soil moisture, temperature, humidity, and wind direction (Downs and Stocks 1978).

Table 25. Atmospheric emissions from a 5,730 MT (6,300 T) per day coal cleaning and associated activities, assuming no particulate control.[a]

		EMISSION RATES (kg/day)			
Source	Particulates (uncontrolled)	CO	NO_x	SO_2	Hydrocarbons
Primary crushing	284				
Loading and unloading	114				
Thermal drying	320	15.4	278.2	587.3	7.7
Vehicle emissions	1	6.8	11.4	0.8	1.3
Total	719	22.8	289.6	588.1	9.0

---

[a] Original assumptions in the source document included 80% particulate control in crushing transfer operations and 99% control of particulates from thermal dryers.

Source: Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.

Table 26. Analysis of trace element concentrations in emissions from a typical thermal dryer.

Constituent	Concentrations in ppmw Unless Noted Otherwise
Aluminum	1%
Antimony	<50
Arsenic	<100
Barium	200
Beryllium	1
Bismuth	<10
Boron	10
Cadmium	<50
Calcium	3,000
Chloride	40-118
Chromium	30
Cobalt	<10
Copper	30
Fluorine	--
Germanium	<30
Iron	5,000
Lead	<30
Lithium	<10
Magnesium	1,000
Manganese	50-100
Molybdenum	<10
Nickel	20-30
Potassium	1,000-2,000
Selenium	--
Silica	1.5%
Silver	< 1
Sodium	300
Sulfate	1,040-3,920
Strontium	100
Tellurium	<100
Tin	<50
Titanium	500
Vanadium	50
Zinc	<100
Zirconium	10

Source: US Environmental Protection Agency. 1974. Background information for standards of performance: coal preparation plants. Volume 1: proposed standards. US Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park NC, EPA-450/2-74-021a, 40 p.

Table 27. Polycyclic organic materials emitted from coal refuse fires.

Dibenzothiophene
Anthracene/phenanthrene
Methylanthracenes/phenanthrenes
9-Methylanthracene
Fluoranthene
Pyrene
Benzo(c)phenanthrene
Chrysene/benz(a)anthracene
Dimethylbenzanthracenes (isomers)
Benzo (k or b) fluoranthene
Benzo(a)pyrene/benzo(e)pyrene/perylene
3-Methylcholanthrene
Dibenz(a, h or a,c)anthracene
Indeno (1,2,3-c, d)pyrene
7H-Dibenzo(c, g)carbazole
Dibenzo (a, h or a, i)pyrene

Source: Chalekode, P. K., and T. R. Blackwood. 1978. Source assessment: coal refuse piles, abandoned mines and outcrops, state of the art. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-78-004v, 39 p.

Table 28. Lift velocities of dry dusts.[a]

Particle Size (μm)	Air Velocity, m/s Granite	 Silica	 Coal
75 - 105	7	6	5
35 - 75	6	5	4
10 - 35	4	3	3

[a] Add 1 m/s (3 ft/s) for wet dusts.

Source: Down, C. G. and J. Stocks. 1978. Environmental impact of mining. Applied Science Publishers Ltd. London, England. 371 p.

2.1.1.1.3. Dispersion of Emissions

The dispersion of thermal dryer emissions in the atmosphere is controlled by environmental factors as well as design considerations for thermal dryer exhaust systems (Dvorak and Lewis 1978). Key environmental factors include:

- Topography -- Local terrain features affect the direction and speed of near-ground winds. Higher elevations upwind from an exhaust stack can cause a local downwash of emissions (Figure 42). Higher elevations downwind from the stack may intercept the emission plume, resulting in a truncated dispersion pattern. Cold, night air that settles to valley floors may force the plume to flow through local valleys (Figure 43). The restricted air circulation pattern of valleys can increase the ambient concentration of pollutant emissions locally.

- Meteorology -- Three meteorological factors control the dispersion of stack emissions:

  -- Wind directions above and below the plume determine the ultimate direction of plume dispersion. Changing wind directions cause the path of the plume to widen and change direction.

  -- Wind speeds affect the final ground-level concentrations and ultimate stack-to-ground travel times of emitted pollutants. High wind speeds dilute the pollutants but also increase travel time, thus allowing increased opportunities for chemical reactions between airborne pollutants and local air resources.

  -- Turbulence in the atmosphere increases the mixing and dilution of emission plumes. Near-ground turbulence usually is induced by the flow of air over rough terrain or by thermal convection caused by stratified temperature differences between the upper and lower portions of the atmosphere.

2.1.1.2. Water Discharges

The quantity and quality of wastewater generated by an active underground coal mine generally are functions of local hydrogeology, precipitation, and runoff characteristics. The local hydrologic regime should be described thoroughly to identify the hydrologic variables that interface with process- and site-related wastewaters (Figure 44). The resource elements to be addressed in an environmental inventory to support a new source NPDES application appear below.

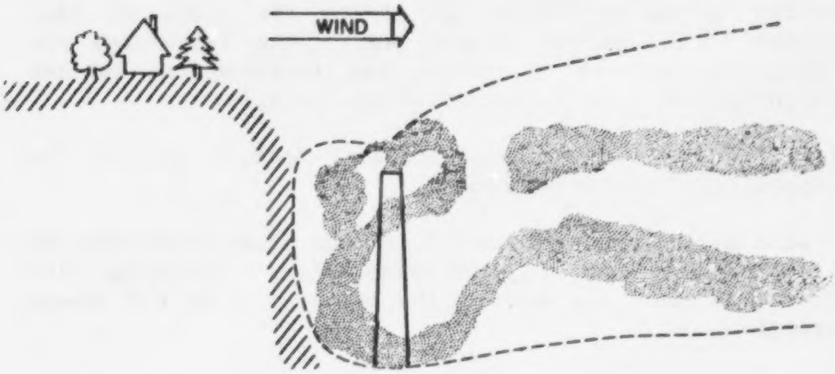


Figure 42. Downwash of plume caused by local terrain features.

Source: Dvorak, A. J. and B. G. Lewis. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. US Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Washington DC, FWS/OBS-78/29, 360 p.

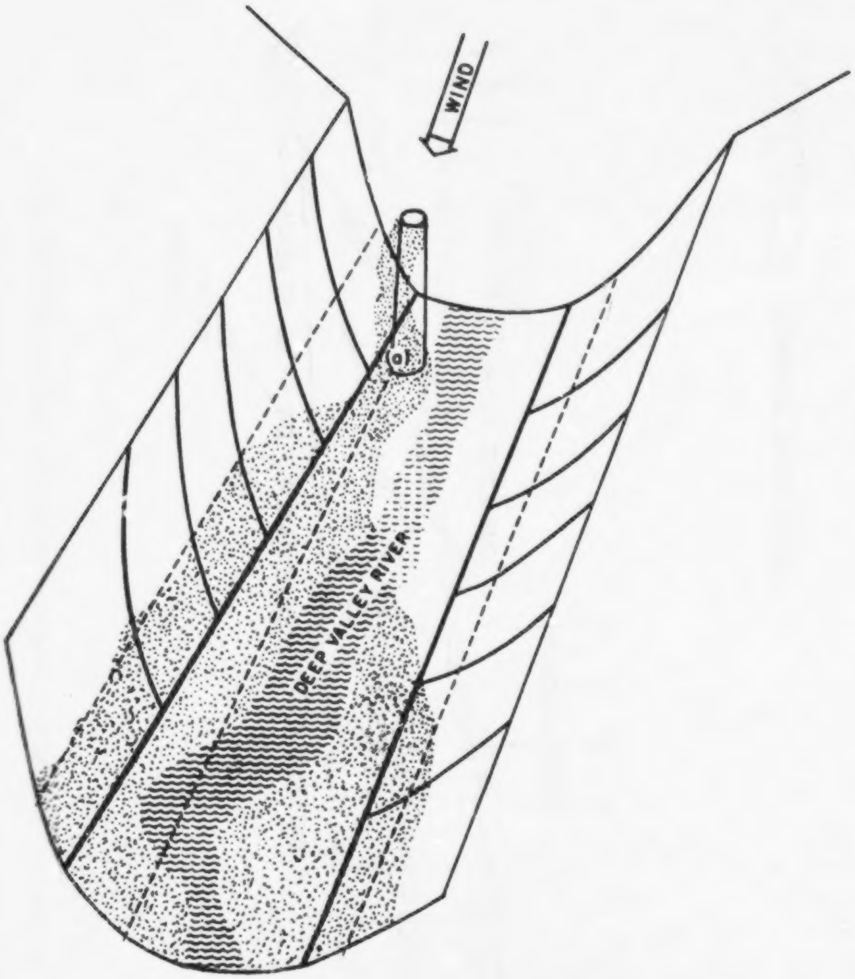


Figure 43. Flow of plume caused by drainage of cold air through a valley.

Source: Dvorak, A. J. and B. G. Lewis. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. US Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Washington DC, FWS/OBS-79/29, 360 p.

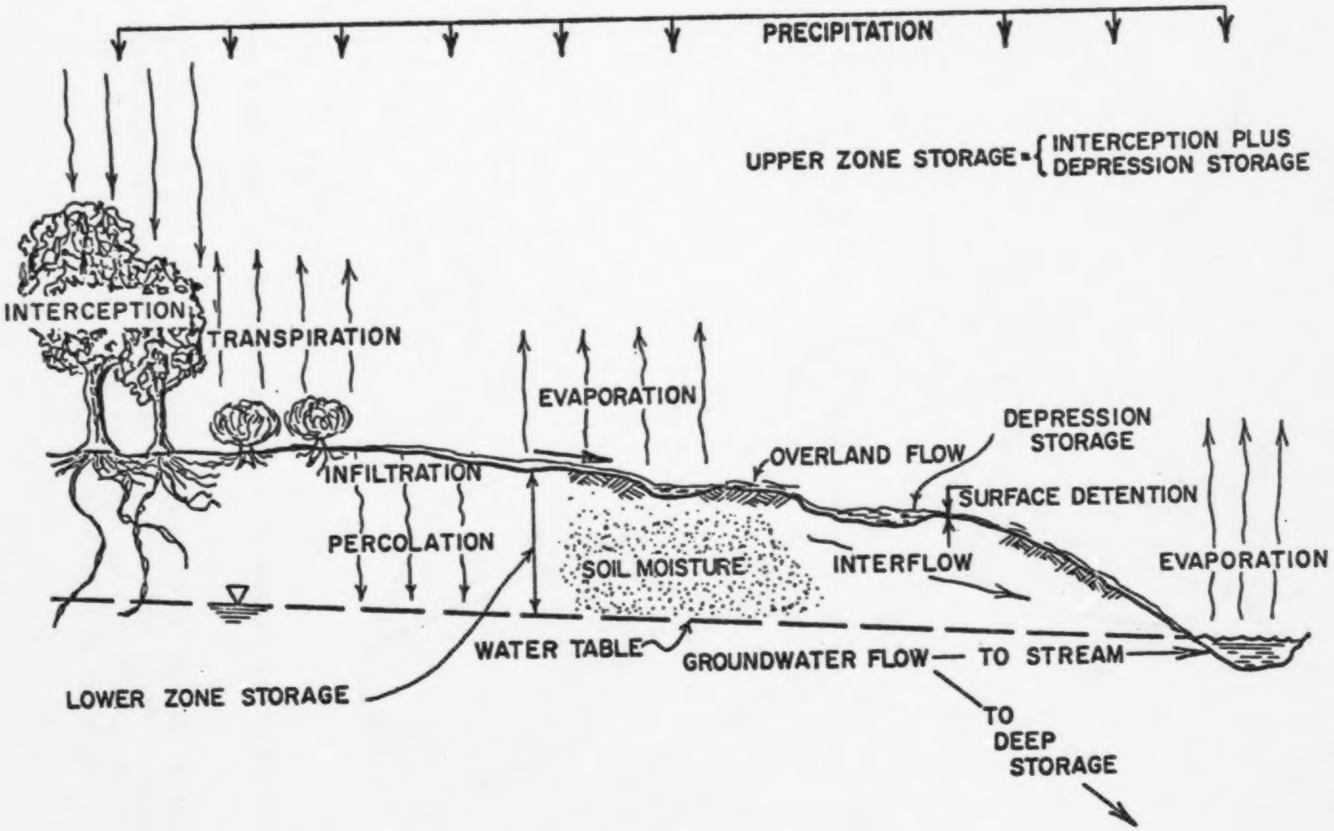

PRECIPITATION
UPPER ZONE STORAGE = { INTERCEPTION PLUS DEPRESSION STORAGE
INTERCEPTION
TRANSPIRATION
EVAPORATION
DEPRESSION STORAGE
OVERLAND FLOW
SURFACE DETENTION
INFILTRATION
PERCOLATION
SOIL MOISTURE
INTERFLOW
EVAPORATION
WATER TABLE
GROUNDWATER FLOW — TO STREAM
LOWER ZONE STORAGE
TO DEEP STORAGE

Figure 44. The hydrologic cycle, including all major components of the hydrologic regime.

Source: Shumate, Kenesaw S., E. E. Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH. EPA-600/2-76-112, 476 p.

- Groundwater - maps, text, and cross sections that describe:

  -- Depth, extent, storage and transmission capacities, and water quality of all aquifers and confining strata that will be disturbed during development, extraction, and abandonment of the underground mine

  -- Local groundwater use characteristics, including well locations, ownership, withdrawal rates, and planned or projected increases in local groundwater demand

  -- Identification of aquifer recharge areas for all aquifers that are to be disturbed, with special attention to on-site recharge areas.

- Surface water - maps, text, and cross sections that describe all receiving waters to be affected by proposed underground mining and cleaning operations. Receiving waters include:

  -- seeps
  -- springs
  -- streams
  -- impoundments
  -- wetlands

  The description of surface water hydrology should include descriptions of:

  -- drainage basin areas
  -- low flow of streams
  -- mean flow of streams
  -- flood flow of streams
  -- flood control plans
  -- flood control structures

  Surface waters should be characterized by their chemical quality. Stream segments and lakes that are classed as effluent limited, water quality limited, or as having some other use-oriented or physical/chemical water quality classification should be identified. The chemical quality of receiving waters should be characterized on a seasonal basis by the following parameters.

  -- temperature
  -- pH
  -- acidity
  -- alkalinity
  -- hardness
  -- dissolved oxygen
  -- total suspended solids
  -- total dissolved solids

-- turbidity
-- sulfate
-- ammonia
-- concentrations of total dissolved iron, manganese, zinc, aluminum, and nickel

To assess the effects of wastewater discharges on the local aquatic community, seasonal, quantitative baseline data should be compiled that describe adequately the biota of local receiving waters. Biota should be sampled both upstream and downstream from proposed discharge points and the presence of spawning beds should receive particular attention. The possible occurrence of unusual or endangered species of aquatic organisms should receive special attention during the inventory.

Appropriate biota include, but are not limited to:

-- phytoplankton
-- macrophytes
-- invertebrates
-- fish

Water discharges from proposed underground coal mining and cleaning facilities should be characterized by source, quantity, and quality. These considerations are described below.

2.1.1.2.1. Wastewater Sources

Wastewater associated with underground coal mining generally occurs as nuisance water which must be managed effectively to avoid disruption of the mining operation. Groundwater, which is held in fractures and voids in geologic material, normally is encountered during excavation for mine development or coal recovery. Coal seams locally may be significant sources of groundwater supplies. These coal seams generally have well-developed fracture systems, and overlie relatively impermeable shales, clays, or claystones.

The hypothetical hydrologic regime of an unmined watershed is diagrammed in Figure 45. Water from precipitation percolates downward and laterally to recharge the base level of the nearby stream. Additional precipitation flows downhill through the upper 0.3 to 1 m (1 to 3 ft) of soil. Excess precipitation flows over the ground surface as runoff.

The base flow of a stream represents the contribution of groundwater to streamflow. Groundwater may seep to the surface along the contact zones of geologic materials with different water-bearing capabilities. The groundwater may enter a stream directly through the subsurface or flow downhill through seeps, gullies, and depressions to stream headwaters.

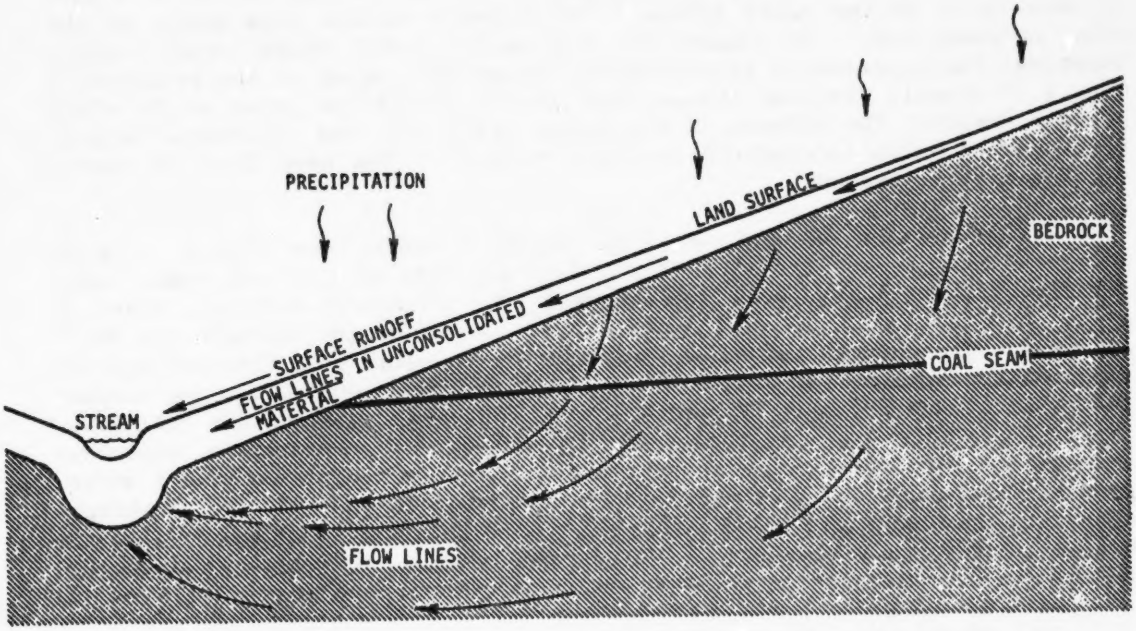

PRECIPITATION
LAND SURFACE
BEDROCK
SURFACE RUNOFF
FLOW LINES IN UNCONSOLIDATED MATERIAL
COAL SEAM
STREAM
FLOW LINES

Figure 45. Idealized hydrology of a coal bearing watershed before mining.

Source: US Environmental Protection Agency. 1977. Elkins mine drainage pollution control demonstration project. US Environmental Protection Agency, Resource Handling and Extraction Division, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-77-090, 316 p.

The depth of the local water table in part determines the amount of water that infiltrates through the surface. An increase in the depth of the watertable can result in a higher capacity for temporary water storage by unconsolidated materials near the surface. As the water-storage capacity of the surface material increases, the amount of water that infiltrates the surface during gentle storms of long duration also may increase. The increased infiltration of water through the surface depletes the amount of excess precipitation available for runoff.

An active coal mine may be idealized as a shaft at the center of a cone of depression in the water table. The diameter of the cone grows as the mine is dewatered. In Figure 46, the successively deeper shaft levels represent the progressive extraction of deeper coal seams or the progressive mining of steeply pitching seams. The cone of depression grows as the shaft becomes deeper. The effects of dewatering eventually are noticeable in privately owned wells located off the mine property. The base flows of nearby streams may be lowered.

The excavation of coal or other strata disrupts the natural flow of water through the subsurface. On the down-dip side of the coal seam, water percolates through fractured overburden to the mined-out workings, where it mixes with mine drainage and subsequently is discharged through the drift entryway. The quantity of water contributing to local base flow and aquifer recharge is reduced, and the recharge to receiving waters may be contaminated with mine drainage (Figure 47). On the up-dip side of the coal seam, water percolates through fractured overburden and enters the mined-out underground workings. Most of this water flows down-dip toward the underground mine pool which forms at the down-dip extent of the workings. Recharge from percolating groundwater is minimal to aquifers below the mined-out workings (Figure 48). Water from the mine pool may be discharged to the surface through fractures or voids in natural geologic materials.

The subsidence of natural materials into underground workings may increase the permeability of unconsolidated materials near the surface, producing an increase in the rate of water infiltration through the surface. The scarps, fractures, sinkholes, and other surface features of subsidence may interdict the flow of surface waters, routing the streamflow into the subsurface (Hill 1978).

Coal cleaning facilities that use water for process operations generally do not produce process-related water discharges (USEPA 1976d). The wastewater sources associated with coal cleaning operations that generally generate effluent for discharge include surface areas (parking lots, refuse piles, and other ancillary areas) that are affected by runoff (40 CFR 434; 44 FR 9:2586-2592, 12 January 1979).

2.1.1.2.2. Wastewater Quantities

The quantity of groundwater that may require handling and possible treatment for discharge may be estimated from the results of an aquifer test

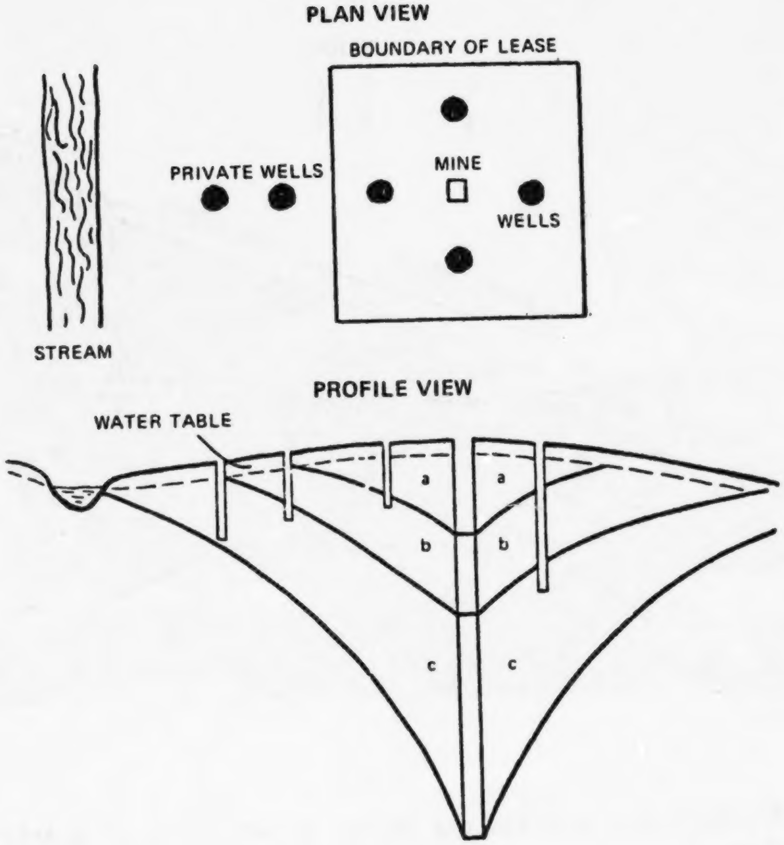

PLAN VIEW
BOUNDARY OF LEASE
PRIVATE WELLS
MINE
WELLS
STREAM
PROFILE VIEW
WATER TABLE
a
a
b
b
c
c

Figure 46. Progressive dewatering of an aquifer with excavation of a mine shaft.

Source: Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for the US Environmental Protection Agency, National Environmental Research Center, Las Vegas NV, 84 p.

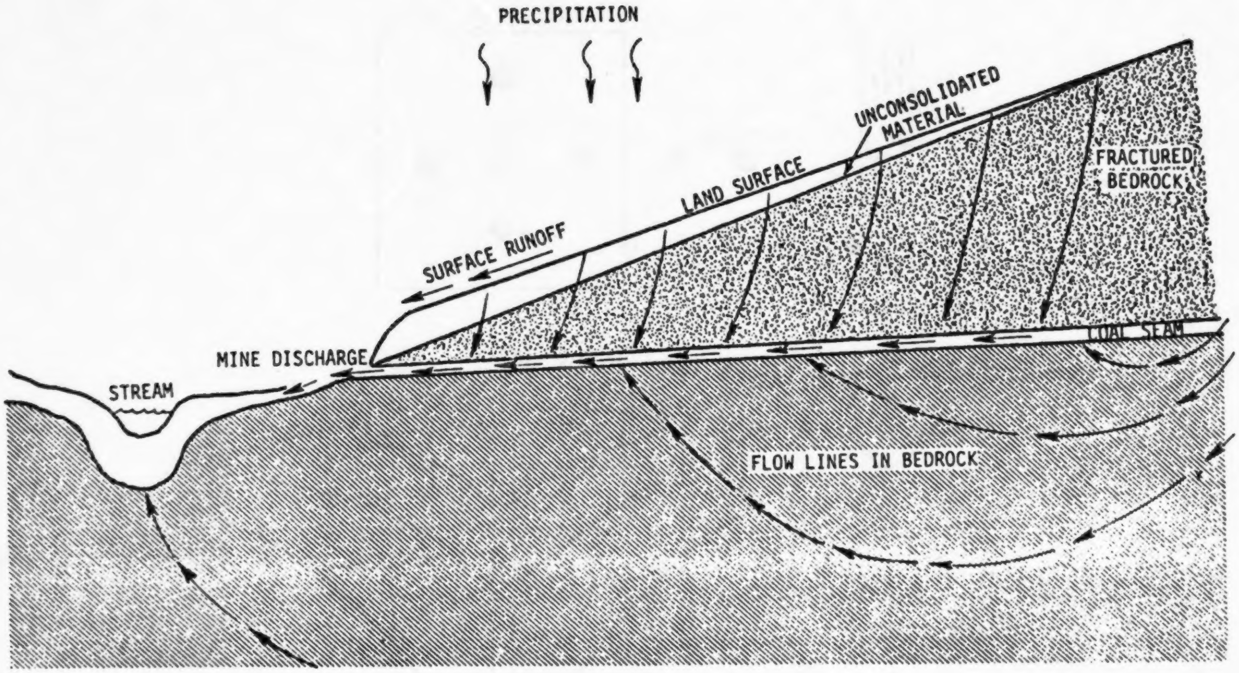

PRECIPITATION
UNCONSOLIDATED MATERIAL
FRACTURED BEDROCK
LAND SURFACE
SURFACE RUNOFF
COAL SEAM
MINE DISCHARGE
STREAM
FLOW LINES IN BEDROCK

Figure 47. Post mining hydrology on the downdip side of a drift mouth mine.

Source: US Environmental Protection Agency. 1977. Elkins mine drainage pollution control demonstration project. US Environmental Protection Agency, Resource Handling and Extraction Division, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-77-090, 316 p.

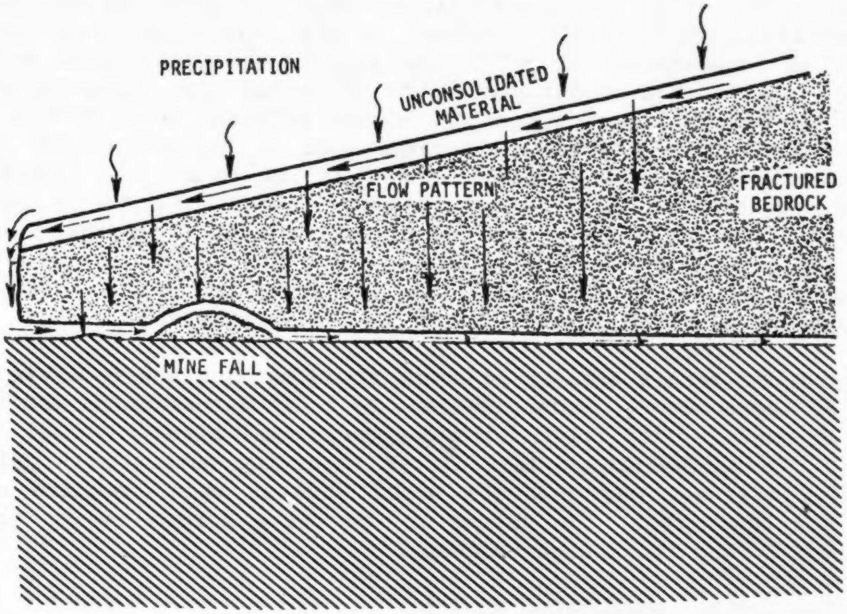

PRECIPITATION
UNCONSOLIDATED MATERIAL
FLOW PATTERN
FRACTURED BEDROCK
MINE FALL

Figure 48. Post mining hydrology on the updip side of an underground mine.

Source: US Environmental Protection Agency. 1977. Elkins mine drainage pollution control demonstration project. US Environmental Protection Agency, Resource Handling and Extraction Division, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-77-090, 316 p.

(Walton 1970, Lohman 1972). One well is pumped at a known rate and water levels are monitored in surrounding observation wells. The results of the test are analyzed graphically or numerically to quantify the ability of the aquifer to store and transmit water. These coefficients lead directly to estimates of groundwater quantities in situ and rates of water migration toward dewatering centers (Walton 1970, Lohman 1972). Other methods of field investigation include pressure tests and drill stream tests. Water-bearing capacities of rocks also may be estimated from laboratory tests for permeability, porosity, and structural properties (Loofbourow 1973).

Runoff from areas to be affected by proposed underground coal mines and coal cleaning facilities can be calculated using accepted engineering practices (Chow 1959, USSCS 1972). Changes in the topography, land cover, or water table of a watershed may affect the pattern and quantity of runoff and streamflow locally. The amount and volume of runoff from alternate drainage configurations in the proposed permit area and adjacent areas should be calculated to assess the effects of proposed coal mining activities on local surface water hydrology. Figure 49 shows a typical mine site configuration over three subbasins in an affected drainage basin. Runoff is calculated separately for the subbasins. The runoff patterns of Subbasins A and B in Figure 49 may change as the basins are mined. The runoff pattern of Subbasin C is unaffected by mining activity, although streamflow characteristics through the subbasin may be altered by mining upstream.

The proposed permit area or adjacent areas may include receiving waters that require impoundment, channelization, or other interdiction for the construction of surface facilities for underground coal mines and coal cleaning operations. Contamination of interdicted receiving waters with pollutant-bearing mine drainage may generate waste streams which require adequate treatment for discharge. The volume of the waste stream can be predicted and minimized during the design process.

2.1.1.2.3. Wastewater quality

The US coal mining industry produces four basic types of effluents (USEPA 1976a):

- Raw discharge effluent -- untreated mine drainage that generally does not require neutralization and/or sedimentation
- Sediment-bearing effluent -- mine drainage which has been passed through settling ponds or basins without a neutralization treatment
- Acid mine drainage -- untreated mine drainage characterized as acid with high iron content, requiring neutralization and sedimentation treatment

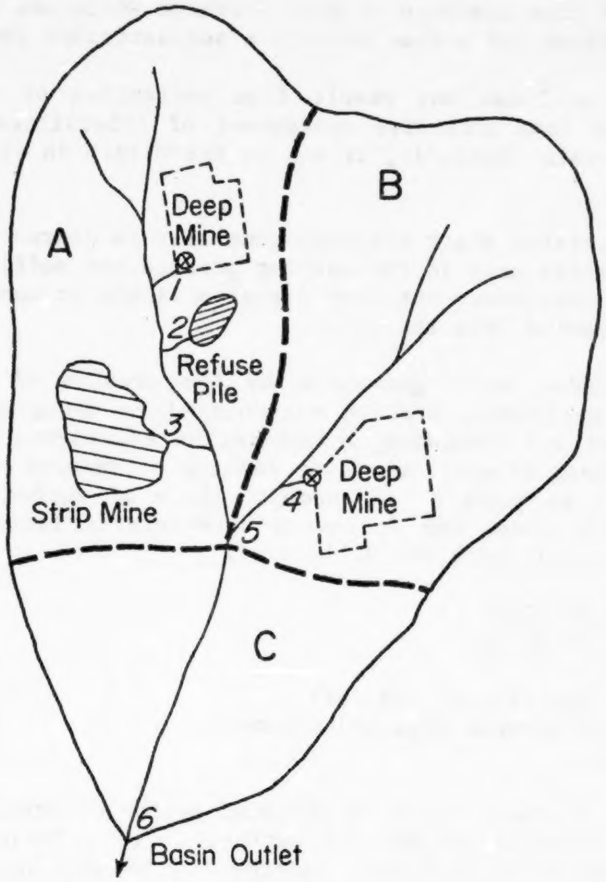

A
B
Deep Mine
1
2
Refuse Pile
3
Strip Mine
4
Deep Mine
5
C
6
Basin Outlet

Figure 49. Subbasins of a watershed.

Source: Shumate, Kenesaw S., E. E. Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112, 476 p.

- Treated mine drainage -- mine drainage which has been pH-neutralized and passed through a sedimentation process.

Discharge effluent may result from collection of runoff from undisturbed areas or from effective management of interdicted receiving waters. So long as it meets standards, it may be discharged in its raw state without treatment.

Coal preparation plant effluent generally is characterized as sediment-bearing. The media used in the washing process are sufficiently alkaline to meet discharge standards, but they dissolve little or none of the extraneous matter being removed from the coal.

Sediment-laden water generated by the erosion of exposed land is a common, but significant, problem encountered in managing surface-disturbed areas. Erosion and resulting sedimentation contribute to water pollution and cause the loss of soil nutrients leading to reduced soil productivity. To characterize adequately the susceptibility of surface-disturbed land to erosion and soil loss, the following site-related factors should be documented and analyzed (Grim and Hill 1974):

- Degree of slope
- Length of slope
- Climate
- Amount and rate of rainfall
- Type and percent vegetation cover
- Soil type

Acid mine drainage (AMD) is produced by the oxidation of pyritic materials to form ferric hydroxide and sulfuric acid. These pollutants contaminate runoff and mine drainage, causing low pH and high concentrations of heavy metals such as iron, manganese, copper, and zinc (Table 29). The amount and rate of acid formation and the chemical quality of the drainage are functions of the amount and type of pyrite in the overburden and coal, other geological and chemical characteristics of the overburden, and the amount of water and air available for chemical reaction.

Raw mine drainage may be alkaline in areas where the overburden contains alkaline material such as limestone or where no acid-producing material is associated with the overburden or coal seam. These discharges usually are high in sulfates and generally are less detrimental to the environment than acid mine discharges (Table 30).

Untreated acid mine drainage has destroyed productivity in approximately 17,700 km (11,000 mi) of US streams (USOSM 1978a:BIII-33). For the Appalachian Region, it is estimated that a residual acid load in excess of 270,000 MT (300,000 T) per year is not neutralized until it reaches the larger streams. In Appalachia, approximately 97% of the acid pollution in streams and 63% in impoundments are generated by coal mining operations (USOSM 1979).

Table 29. General chemical characteristics of raw acid mine drainage.

Parameter	Minimum (mg/l)	Maximum (mg/l)	Mean (mg/l)	Std. Dev.
pH	2.6	7.7	3.6	
Alkalinity	0	184	5	32
Total Iron	0.08	440	52.01	101
Dissolved Iron	0.01	440	50.1	102.4
Manganese	0.29	127	45.11	42.28
Aluminum	0.10	271	71.2	79.34
Zinc	0.06	7.7	1.71	1.71
Nickel	0.01	5	0.71	1.05
Total Diss. Solids	120	8,870	4,060	3,060
Total Susp. Solids	4	15,878	549	2,713
Hardness	24	5,400	1,944	1,380
Sulfate	22	3,860	1,842	1,290
Ammonia	0.53	22	6.48	4.70

Table 30. General chemical characteristics of raw alkaline mine drainage.

Parameter	Minimum (mg/l)	Maximum (mg/l)	Mean (mg/l)	Std. Dev.
pH	6.2	8.2	7.7	
Alkalinity	30	860	313	183
Total Iron	0.02	6.70	0.78	1.87
Dissolved Iron	0.01	2.7	0.15	0.52
Manganese	0.01	6.8	0.61	1.40
Aluminum	0.10	0.85	0.20	0.22
Zinc	0.01	0.59	0.14	0.16
Nickel	0.01	0.18	0.02	0.04
Total Diss. Solids	152	8,358	2,867	2,057
Total Susp. Solids	1	684	96	215
Hardness	76	2,900	1,290	857
Sulfate	42	3,700	1,297	1,136
Ammonia	0.04	36	4.19	6.88

Source: US Environmental Protection Agency. 1976c. Development document for interim final effluent limitation guidelines and new source performance standards for the coal mining point source category. EPA-440/1-76-057a. Washington DC, 288 p.

The quality of mine drainage which has been treated by neutralization and sedimentation to achieve new source discharge limitations generally is acceptable for discharge, although generally inferior to that of raw discharge effluent and sediment-bearing effluent regardless of the neutralization techniques used (USEPA 1976c). The USEPA or State regulatory authorities may require, on a case by case basis, that concentrations of pollutants in discharged wastewater be less than those required by the NSPS. These more stringent limitations may be necessary to protect streams with spawning beds, endemic species, high quality, poor buffering capacity, or existing pollutant concentrations that are mandated for reduction under the CWA.

2.1.1.3. Solid Wastes

Solid wastes from coal cleaning facilities and underground coal mines are characterized by quantity, quality, and particle size.

- Quantity -- At combined coal preparation and underground mining operations, coal cleaning generally yields 80% of the total volume of above-ground solid waste. Quantities of solid wastes expected from cleaning operations can be predicted by comparing the results of coal washability tests with estimated mine production (Keller and others 1968, Ven Kateson 1978, McCandless and Shaver 1978).

- Quality -- Mine wastes from western coal seams generally are alkaline, have a high pH, and contain numerous dissolved substances usually as salts. Mine wastes from eastern coal seams generally contain unstable sulfide minerals (especially pyrite and marcasite) which can produce leachate with low pH and high concentrations of sulfate and heavy metals (W. A. Wahler and Associates 1978).

- Particle size -- Solid wastes from underground coal mining and coal cleaning operations are classified as fine or coarse on the basis of particle size distribution (Chalekode and Blackwood 1978).

  -- Coarse refuse includes material larger than 0.38 cm (0.15 in). This refuse is separated from ROM coal during the coal cleaning process. Waste rock from the development of underground openings also accumulates as coarse refuse. Coarse refuse from underground mines also may include extraneous material such as brattice cloth from mine ventilation systems, oily rags, used mine timbers, and miscellaneous trash.

  -- Fine refuse includes material smaller than 0.38 cm (0.15 in) from fine coal cleaning and desliming operations and residuals from effluent treatment systems.

2.1.2. Treatment Residuals

Treatment residuals from coal mine and preparation plant pollution control systems generally include sludges and solid wastes from treatment facilities and settling ponds. Thermal dryers equipped with fabric filters or other dust suppression devices also generate solid wastes, usually as fine particles, grit, or dust. The waste treatment systems that produce treatment residuals are described in Section 3.2. Waste quantities can be identified by comparing the mass balance (stoichiometry) of the treatment reaction with quantified loadings of materials that will precipitate or settle into the treatment systems (Aplan and Hogg 1979).

2.2 ENVIRONMENTAL IMPACTS OF COAL INDUSTRY WASTES

Emissions, effluents, and solid wastes from underground coal mining and coal cleaning operations may contain pollutants that affect human health and environmental quality adversely. The lethality, toxicity, or other undesirable characteristics of a pollutant may depend on its ambient concentration, method of dispersion (air and/or water), and potential for synergistic effects with other pollutants.

2.2.1. Human Health Impacts

The principal effects on human health from the pollutants found in coal are described below:

- Fugitive dust can result in ambient air quality which is hazardous to humans working near or living downwind from the emissions source. Respired dust can contribute to a decrease of effective volume for air intake to the lungs. The precise health effects of a fugitive dust depend on its composition (Chalekode and Blackwood 1978).

- Sulfates can cause both a bad taste and laxative effect in drinking water. USEPA (1976d) recommends an upper limit of 250 mg/l to provide reasonable protection to humans from these adverse effects.

- Iron concentrations that exceed 30 mg/l in domestic water supplies generally produce objectionable taste, color, and aesthetic characteristics (USEPA 1976d).

- Manganese poisoning from contaminated drinking water has been reported (USEPA 1976c). The acceptable upper limit for manganese in domestic water supplies is 0.5 mg/l, primarily based on aesthetic and taste considerations (USEPA 1976d).

- Zinc concentrations in excess of 5 mg/l can cause an undesirable taste in public water supplies. In addition, zinc at high concentrations can have an adverse effect on humans (USEPA 1976c).

- Trace elements that are found in coal can have adverse effects on human health. Table 31 presents a summary of trace metals, their associated health problems, and pertinent references for more detailed documentation.

- Polycyclic organic materials (POM's) from coal combustion may be carcinogenic (Chalekode and Blackwood 1978). POM's that are known to be carcinogenic include:

  -- Benzo(c)phenanthrene

  -- Dimethylbenzanthracenes (isomers)

  -- Benzo(a)pyrene/benzo(e)pyrene/perylene

  -- Dibenz(a,h or a,c)anthracene

  -- 7H - Dibenzo(c,g)carbazole

  -- Dibenzo(a,h or a,i)pyrene

2.2.2. Biological Impacts

Aquatic and terrestrial biota may be affected adversely by the pollutants which are commonly found in wastes from underground coal mining and coal cleaning operations. The pollutants that are known to produce adverse effects are highlighted below.

- Sediment is transported by water during erosion and by air as fugitive dust. If uncontrolled, sediment transported by runoff may degrade receiving waters by causing increases in turbidity, oxygen demanding materials, nutrients, and potentially toxic substances. Increased sediment loads to receiving waters also hasten the aging of ponds and lakes through filling and nutrient enrichment.

  Aquatic organisms are affected adversely by excess sediment. Increased suspended sediment loads reduce primary productivity (photosynthesis) in surface waters by limiting the penetration of light. Sedimentation buries and suffocates the organisms of the periphyton and macroinvertebrates which have limited mobility, and it reduces or eliminates fish spawning success. Physical abrasion from suspended sediments also destroys aquatic organisms. As sediment load increases in streams, the interstices between the gravel and rocks which compose the bottoms of

Table 31. Effects on human health produced by trace metals in coal.

Metal or Metal Compound	Health Problems	Reference
Arsenic	Cancer of the skin	(Wickstrom 1972); (Lee and Fraumeni 1969)
Beryllium and compounds	Carcinogenesis; Poisoning	(Reeves et al. 1967); (Wager et al. 1969)
Cadmium	Prostate cancer	(Pott 1965); (Kipling and Waterhouse 1967)
Chromium and compounds	Carcinogenesis	(Hueper 1961)
Cobalt	Carcinogenesis	(Gilman and Ruckerbauer 1963)
Lead and compounds	Nasal cancers	(Zawirsica and Medras 1968)
Mercury and compounds	Mutagenic and teratogenic effects	(D'Itri 1972)
Nickel	Nasal cancers	(Gilman and Ruckerbauer 1963)
Nickel carbonyl	Suspected carcinogenesis	(Sunderman and Donnelly 1965); (Cavanaugh 1975)
Vanadium	Inhibition of lipid formation	(Stokinger 1963)
Antimony, arsenic, cadmium, cobalt, copper, iron, lead, magnesium, manganese, tin, and zinc oxides	Fume fever	(Waldbott 1973)

riffle areas gradually fill, effectively eliminating many habitats that normally are occupied by a variety of aquatic organisms. Aquatic macroinvertebrates and fish respond to high concentrations of suspended solids by exhibiting increased rates of downstream movement (drift), decreases in population, and changes in community composition (Gammon 1970).

- Acid water discharges can affect aquatic organisms by affecting the permeability of tissue cells adversely; inducing physiological damage in fish; and affecting aquatic plants, algae, and benthic macro-invertebrates adversely (USOSM 1979).

- Iron discharged in untreated wastewater can kill fish by coating their gills with iron hydroxide precipitates (yellow boy). Fish are deprived of food as the iron hydroxide coats stream bottoms, thus eliminating macroinvertebrates and other food organisms (USEPA 1976b USOSM 1978b). USEPA recommends a maximum iron concentration of 1 mg/l for the protection of many forms of freshwater aquatic life, although tolerance to iron varies greatly among aquatic species (USEPA 1976d). The NSPS discharge limitations for iron take into consideration this variability and provide adequate protection for aquatic biota in general, except as described previously (Section 2.1.1.2.3.).

- Manganese acts similarly to iron, both as a direct toxicant to aquatic biota and as a precipitate-former that eliminates bottom-dwelling organisms (USEPA 1977 in USOSM 1978b). There is no specific maximum concentration of manganese in freshwater that is known to protect all aquatic organisms. Concentrations up to 1 mg/l may be safe for aquatic animals (USEPA 1976d). Much lower concentrations, however, may be hazardous to aquatic plants. Concentrations as low as 0.005 mg/l of soluble manganese are toxic to algae (McKee and Wolf 1963).

- Zinc concentrations ranging from 0.1 to 1.0 mg/l in water with a total hardness of 20 mg/l can kill fish by affecting their gills adversely or by acting as an internal poison. The sensitivity of fish to zinc varies with their species, age, condition, and the chemical and physical characteristics of the water. Freshwater plants may be affected adversely by concentrations of 10 mg/l zinc (USEPA 1976c).

2.3. OTHER IMPACTS

Underground coal mining and coal preparation may produce environmental impacts not directly associated with waste streams. These special impact considerations include:

- Storage and handling of coal
- Site preparation and facility construction
- Coal transportation

2.3.1. Special Problems in Storage and Handling of Raw Materials and Products

Storage piles for coal and coal refuse generally are exposed to wind and precipitation, giving rise to fugitive dust and potentially noxious leachate and runoff which must be interdicted and treated as necessary to minimize potential damage to the environment. Methods to characterize the quality and quantity of wastewater from storage piles are available (Monsanto 1978).

2.3.2. Special Problems in Site Preparation and Facility Construction

Coal cleaning facilities and the surface operations of underground coal mines generally occupy areas that otherwise would be available for such land uses as agriculture, forestry, wildlife management, and recreation. This usurpation of open space may produce ecological effects that can be identified on the basis of inventories of the vegetation and wildlife resources of proposed permit areas. Minimum site information requirements for these inventories include:

- Vegetation:
  - -- species composition and distribution of types
  - -- importance as wildlife habitat
  - -- local and regional uniqueness
  - -- noteworthy specimens or associations of plants
  - -- threatened or endangered species
  - -- species of economic importance
- Wildlife -- habitat for resident or migratory
  - -- amphibians
  - -- reptiles
  - -- birds
  - -- mammals
  - -- threatened or endangered species
  - -- game species

Subsidence of unsupported, undermined terrain may restrict the usage of affected surface areas by humans and wildlife.

Subsidence always is a consideration in underground coal mining. Absolute assurance that subsidence will not occur in an area that is mined by underground methods generally is not feasible. To establish a basis for measuring the effectiveness of a permit applicant's proposed plans for the prediction and control of subsidence in the permit area, baseline conditions should be established for the following resource elements.

- Coal seam variables (Section 1.2.1.2.)
- Topography of the affected area
- Geotechnical properties of coal seam and overburden materials:
  - -- Compressive strength
  - -- Mineralogy
  - -- Structure
  - -- Tensile strength

The stresses that are induced at the peripheries of underground openings (Figure 3) eventually equilibrate. To relieve the shear stresses, failure of the roof and overlying strata may occur on line with the periphery of the pillar (Figure 50). Entire pillars may fail under compressive loads that diverge from the ideal pressure arch (Section 1.2.1.2.2.) when acting in natural overburden (Figure 51).

The following discussion of subsidence largely is based on the work of Stefanko (Cummins and McGiven 1973). Additional references to the topic appear in the bibliographic index.

The extent of subsidence over one or more mine openings can be predicted empirically. The arch of compressive forces above a single opening can achieve relatively long-term stability for subcritical widths (-Wc). Subsidence eventually may cause a vertical displacement (S_1) at the surface of the opening. As the opening is widened, the span of the excavated chamber reaches a critical width (Wc) that approximates the maximum pressure arch at which compressive failure of the overburden is imminent. The subsequent vertical displacement (S) is a maximum at the center of the trough (Figure 52). Excavation of the opening to a super- critical width extends the limb of the subsidence trough into the newly undermined overburden. The center of the vertical displacement (S_2) follows the center of the trough as the opening is expanded.

The maximum areal extent of subsidence from an underground opening can be approximated. The limits of the subsidence trough lie within an envelope extended from the peripheries of the opening at the angle of draw, which is measured from a vertical line extended upward from the walls of the opening.

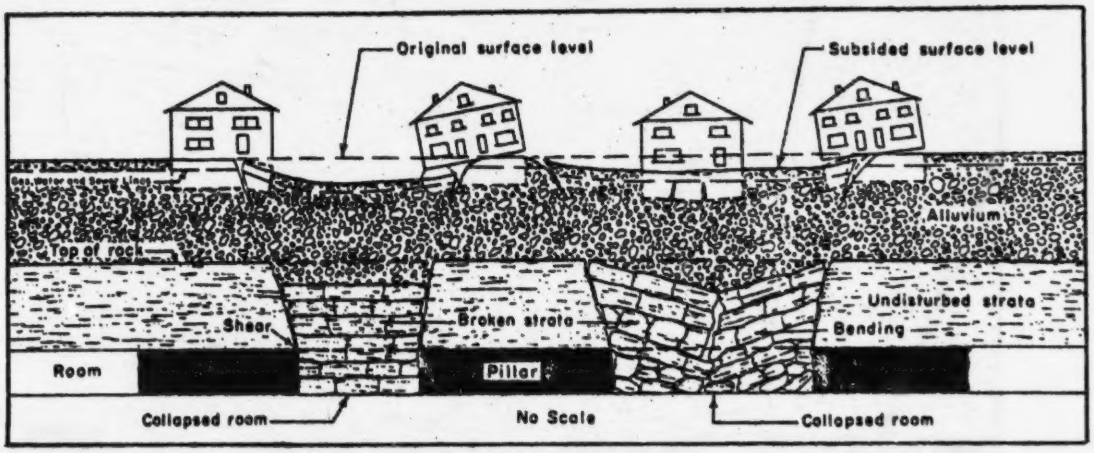

Original surface level
Subsided surface level
Gas, Water and Sewer Lines
Alluvium
Top of rock
Undisturbed strata
Broken strata
Shear
Bending
Room
Pillar
Collapsed room
No Scale
Collapsed room

Figure 50. Subsidence caused by failure in shear stresses along pillar peripheries.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

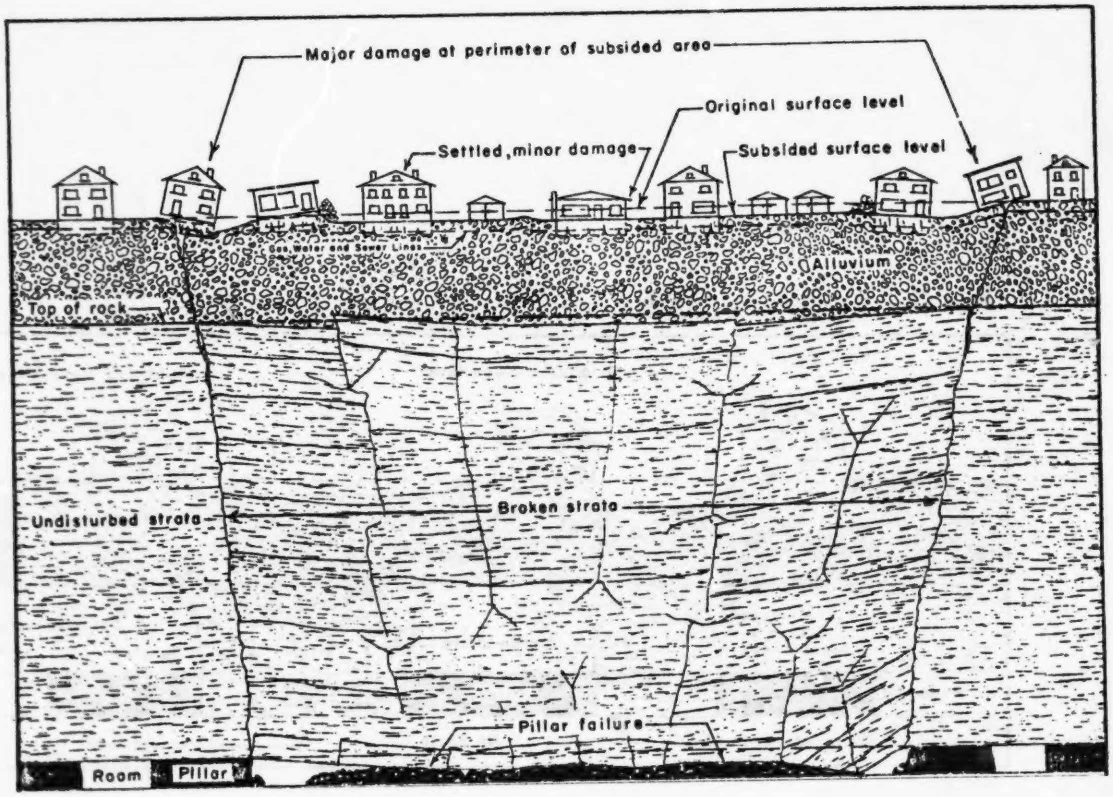

Major damage at perimeter of subsided area
Original surface level
Settled, minor damage
Subsided surface level
Gas, Water and Sewer Lines
Alluvium
Top of rock
Undisturbed strata
Broken strata
Pillar failure
Room
Pillar

Figure 51. Subsidence caused by compressive failure of a coal pillar.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

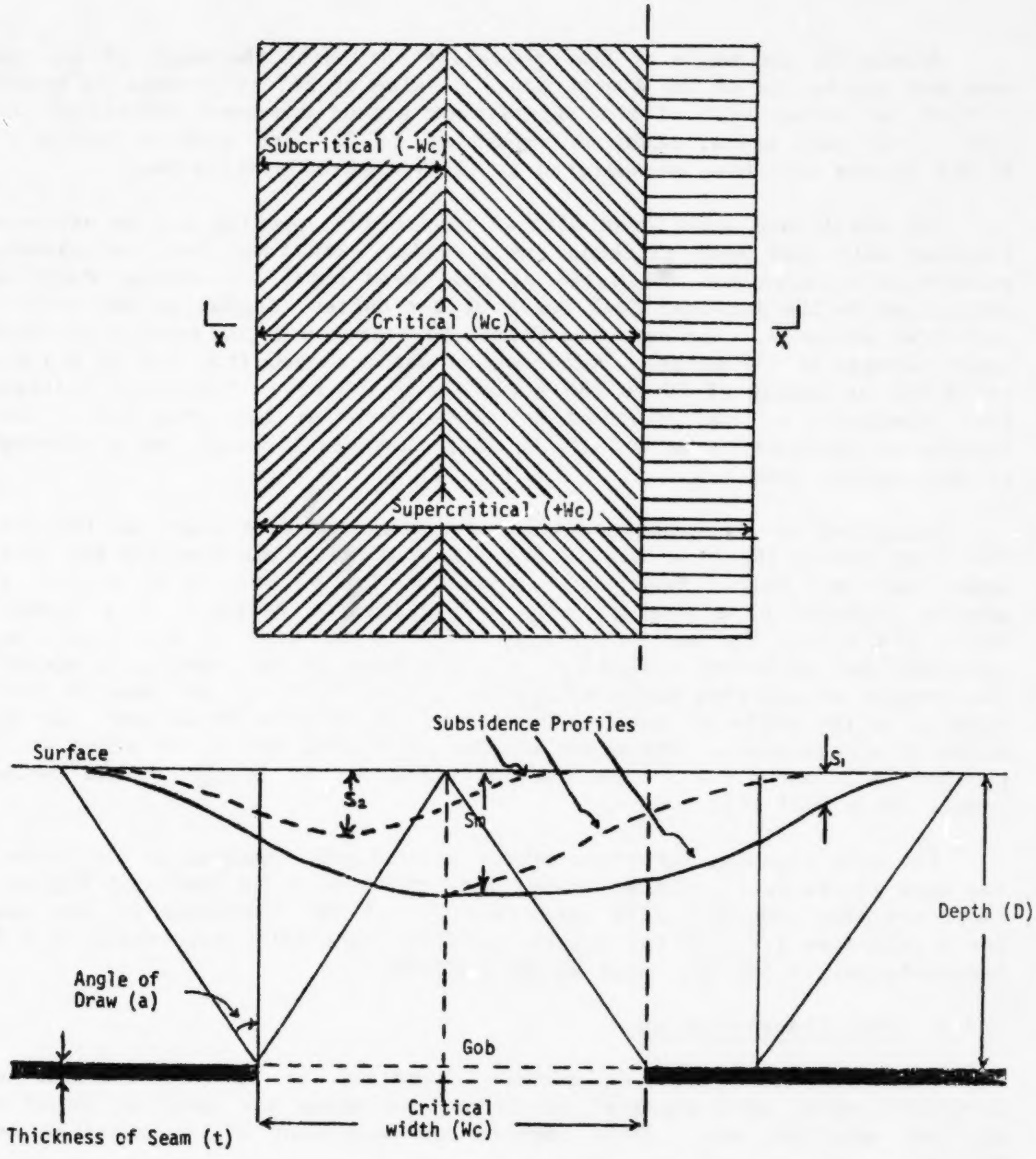

Subcritical (-Wc)
Critical (Wc)
Supercritical (+Wc)
X
X
Subsidence Profiles
Surface
S_1
S_2
Sm
Depth (D)
Angle of Draw (a)
Gob
Thickness of Seam (t)
Critical width (Wc)

Figure 52. Subsidence profiles and the corresponding widths of a single opening.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

Values for the angle of draw generally vary with the depth of the coal seam and the nature of the overburden. A value of 25° is assumed to be sufficient to include all of the significant ground movement associated with most of US coal seams, although values up to 35° are used in Europe and higher values have been encountered at individual US operations.

The subsidence associated with an underground opening can be expressed together with coal seam thickness as a ratio. The functional relationship between this ratio and the ratio of coal seam depth to opening width was determined by the National Coal Board of the United Kingdom on the basis of empirical evidence. The curve in Figure 53 represents the results of subsidence surveys at 157 mines. Thickness of seams ranged from 0.6 to 5.4 m (2 to 18 ft) at depths of 30 to 780 m (100 to 2,600 ft). The curve indicates that subsidence is negligible for width-depth ratios less than 0.25. Total subsidence (assumed to be 90% of the seam thickness) occurs for width-depth ratios greater than 1.3.

Returning to the example developed during the discussion of the pressure arch theory (Section 1.2.1.2.2.), it is possible to quantify the subsidence that may result from the excavation of coal from a 40 m (135 ft) opening (created by mining the ribs and pillars on retreat) at a depth of 240 m (800 ft). The horizontal distance from the tail of the trough to a vertical line projected upward from the periphery of the opening is equal to the tangent of the draw angle multiplied by the depth of the seam (D tan a, where a is the angle of draw). The product is doubled to account for both sides of the opening. The width of the excavation (40 m) is added to the product (2 D tan a + W). The maximum width of the trough at the surface equals 264 m (881 ft).

For this example, the ratio of the width of the opening to the depth of the seam equals 0.17. Comparison of this ratio with the curve of Figure 53 indicates that subsidence is less than 10% of the thickness of the seam. For a coal seam 1.8 m (6 ft) thick, a maximum vertical displacement of 0.2 m (approximately 8 in) may occur at the surface.

2.3.3. Coal Transportation

The coal transportation methods described in Section 1.2.2.1. can adversely affect environmental resources, including air quality, water resources, and land use. These impacts are described in the sections that follow.

2.3.3.1. Air Quality

Trains, barges, and trucks produce emissions from engine exhausts and load loss during transport. Emission rates generally depend on the type of fuel consumed by the carrier and the measures taken (if any) to stabilize or cover the surface of the transported coal.

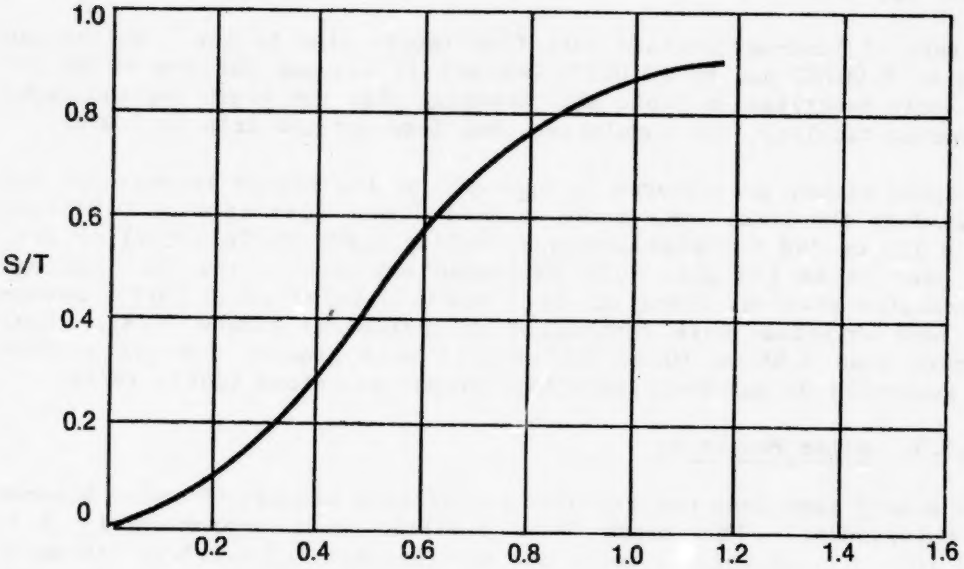


Figure 53. The subsidence-overburden thickness ratio (S/T) expressed as a function of width (W) of the opening and depth (d) of the seam.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

Emission rates were estimated for selected pollutants from unit train and barge operations (Table 32). Emission rates for particulates were estimated as percentages of the loads. Unit trains may lose between 0.05 and 1.0% of loaded coal during transit. Barges travel at lower speeds and therefore lose less coal. An emission rate of 0.01% per day is shown in Table 32 as a cumulative total of 0.02% of the original load, assuming a typical two-day trip.

The rate of load-particulate loss from trucks also is low. An average loss rate of 0.0016% per km (0.0025% per mi) is assumed for the 64 km (40 mi) round trip described in Table 33. Assuming that the truck returns empty to the loading facility, the cumulative load loss for the trip is 0.05%.

Conveyors either are covered or operated at low speeds to minimize the loss of load to the wind. One study assumed a wind loss rate of 0.02% per day from a 122 cm (48 in) wide conveyor hauling 1,800 MT (2,000 T) of coal per hour over 16 km (10 mi). The estimated emission factor for spillage rate at transfer stations along the belt was 0.07 kg/MT (0.15 lb/T), assuming that some emissions were controlled by enclosures (Szabo 1978). Coal sizes larger than 0.95 cm (0.38 in) or coal with greater than 9% surface moisture generally do not contribute to conveyor emissions (USEPA 1977b).

2.3.3.2. Water Resources

Coal slurry pipelines can transfer significant amounts of water between distant watersheds. The Black Mesa pipeline uses approximately 1.2-million l (0.3 million gal) of water per day (Section 1.2.2.1.5.). Assuming a minimum transfer rate of 3.6 million MT (4 million T) per year for economic operation, a coal slurry pipeline will use approximately 1 million l (0.3 million gal) per day to pump a slurry that contains approximately 50% solids by volume. This rate of water use may conflict with existing water uses in arid parts of the Nation (Figure 54).

2.3.3.3. Land Use

The land required for rights-of-way (ROW) varies by transportation mode (University of Oklahoma 1975):

- Conveyor -- 0.9 ha/km (3.64 ac/mi)
- Rail -- 1.5 ha/km (6 ac/mi)
- Coal slurry pipeline -- 2.5 ha/km (10 ac/mi) for a single pipeline; 3 ha/km (12 ac/mi) for two pipelines in one ROW (Szabo 1978)

Table 32. Atmospheric emissions from unit trains and barges hauling coal under assumed conditions.

Pollutant	Quantity (kg per trip) Unit train[a]	Quantity (kg per trip) Barges[b]
CO	935	2,122
NO_x	4,855	3,492
SO_x	780	254
Hydrocarbons	2,075	406
Particulates (engine exhaust)	345	122
Particulates (loading)	2,285	3,630
Particulates (in transit)	[illegible],700	3,600
Particulates (unloading)	[illegible],285	3,630

---

[a] Assumes a 985 km (612 mi) [illegible] to haul 11,430 MT (12,600 T) of coal one [illegible]

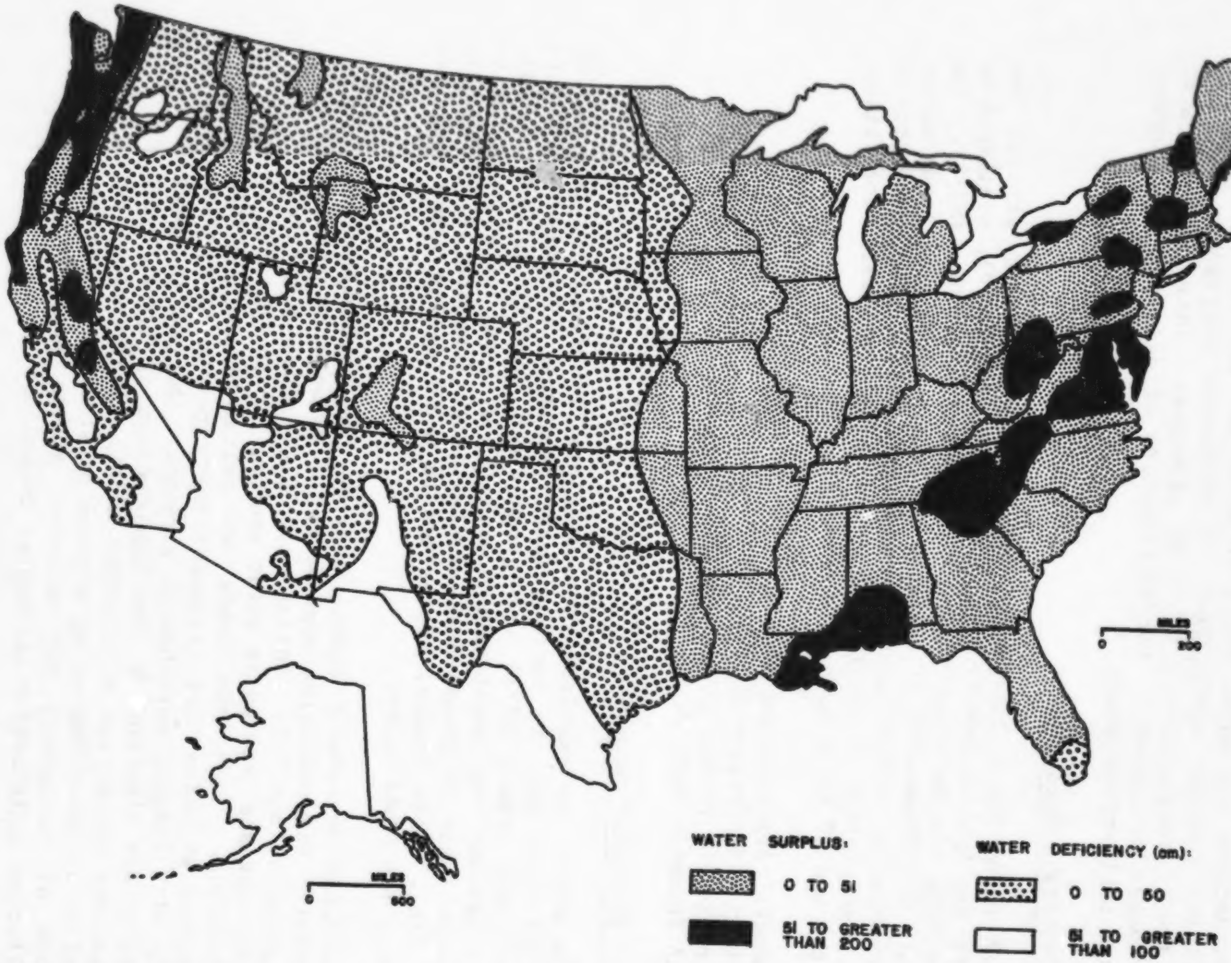
[b] Assumes a 460 km (288 [illegible] way to haul 18,000 MT (20,000 T) of coal.

Source: Szabo, Michael [illegible] vironmental assessment of coal transportation. US Envir[illegible]al Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.

Table 33. Atmospheric emissions from 6.4 km (40 mi) round trip by truck to haul 27 MT (30 T) of coal one way.

Pollutant	Quantity (kg per trip)
CO	0.98
NO_2	1.62
SO_2	0.12
Hydrocarbons	0.16
Aldehydes (HCHO)	0.01
Organic acids	0.01
Particulates (engine exhaust)	0.06
Particulates (loading)	14
Particulates (in transit)	27
Particulates (unloading)	14

Source: Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.



MILES
0
200
MILES
0
600
WATER SURPLUS:
0 TO 51
51 TO GREATER THAN 200
WATER DEFICIENCY (cm):
0 TO 50
51 TO GREATER THAN 100

Figure 54. Abundance of water in the United States.

Source: Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.

2.4 MODELING OF IMPACTS

Models are available to simulate the effects of underground coal mines and coal cleaning facilities on air quality and water resources. Adequate local data must be available to implement these models successfully. Models usually are calibrated with data derived from similar geographic areas and operational situations for which the impacts on air and water quality are known. Models for specific applications in particular geographic areas may be available from Federal, State, or local agencies. These agencies also should be consulted to ascertain the availability of data for the proposed permit area and calibration areas.

2.4.1. Air Quality Models

The USEPA maintains a library of air quality models as part of the User's Network for Applied Modeling of Air Pollution (UNAMAP), available on magnetic tape from the National Technical Information Service (NTIS). The models simulate the dispersion of airborne pollutants from single and multiple point and nonpoint sources using assumptions for wind rose, stability of the plumes, reactivity of pollutants, and other variable conditions. Guidance on the use of these models is available from:

Environmental Applications Branch
Meteorology and Assessment Division (MD-80)
US Environmental Protection Agency
Research Triangle Park NC 27711

2.4.2. Water Resources Models

Numerous models are available that simulate the effects of coal mining and associated land uses on surface water resources (Shumate and others 1976; Sanford and others 1977) and groundwater quality (Libicki 1978). Other models predict the quantitative effects of local groundwater withdrawal rates on regional groundwater availability (Trescott 1975; Trescott and others 1976). Some typical approaches to modeling for water resources management are described below.

- Watershed management models include the delineation of subbasins and pollution sources for a network of streams (Figures 49 and 55). Polluters include mines and refuse piles that are treated as point sources for the purpose of simulation. Pollutant loads are calculated for stream segments at nodes that represent their points of confluence with larger, main-branch streams. Changes in water quality are simulated by the introduction of hypothetical treatment facilities at critical nodes. Achievable water quality is optimized using minimum permissible concentrations of pollutants for selected stream segments and pollution minimization strategies including:

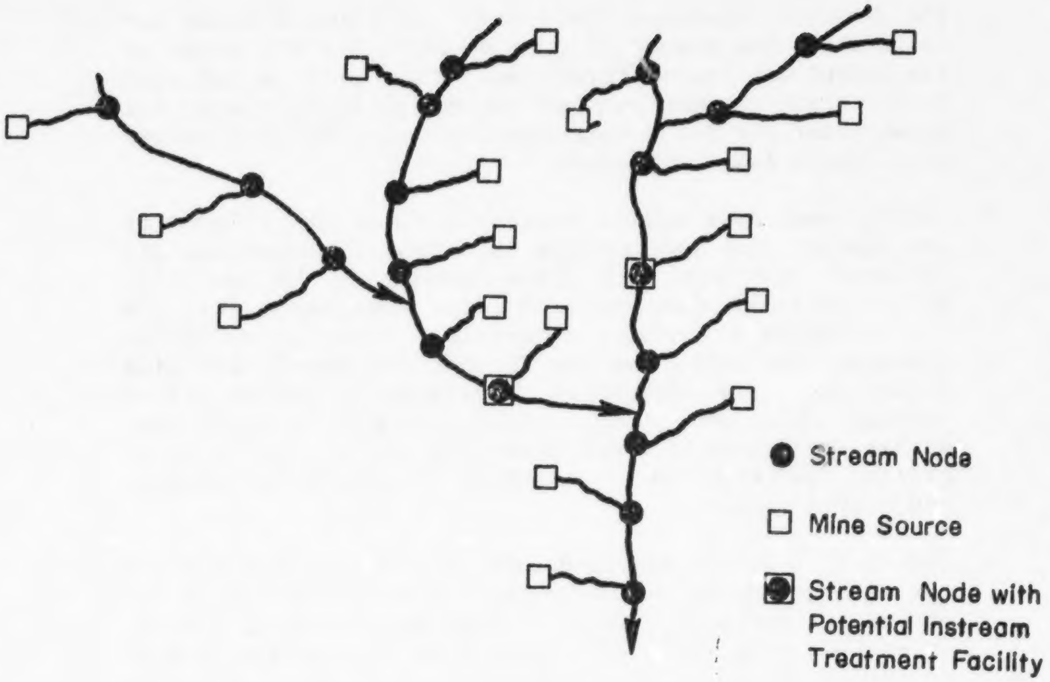

● Stream Node
☐ Mine Source
Stream Node with Potential Instream Treatment Facility

Figure 55. Schematic representation of a watershed for water quality modeling.

Source: Shumate, Kenesaw S., E. E. Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112, 476 p.

-- Abatement at the source

-- Treatment at the source

-- Treatment in the stream channel

The optimal control strategy is chosen on the basis of environmental factors and cost-effectiveness (Shumate and others 1976).

The Stanford Watershed Model (SWM) provides a means for calculating the availability of moisture for all phases of the hydrologic cycle (Figure 56). This model is utilized to calculate the movement and storage of surface water and groundwater for the underground coal mine and coal refuse pile models described below.

- Underground mine source models simulate the effects of groundwater flow and storage on rates of generation and transport for acid and other pollutants (Figure 57). Rates are calculated separately for mine water flow and for oxidation of pyritic materials. Rates of pollutant transport are calculated for flooded and non-flooded mine conditions. The dispersion of pollutants can be traced through mechanisms that include leaching through substrata, diffusion through substrata under the force of gravity, and flushing of substrata by inundation (Shumate and others 1976).

- Refuse pile source models determine acid production rates for discrete areas in the pile. Acid removal rates are determined for each removal mechanism, including runoff, interflow, base flow, and percolation to the groundwater reservoir (Figure 58). Precipitation data including periodicity, intensity, and duration are utilized to simulate the discontinuous nature of acid production and transport under natural conditions. Acid production is assumed to cease during rainfall because of direct blockage of oxygen diffusion to exposed pyritic materials (Shumate and others 1976).

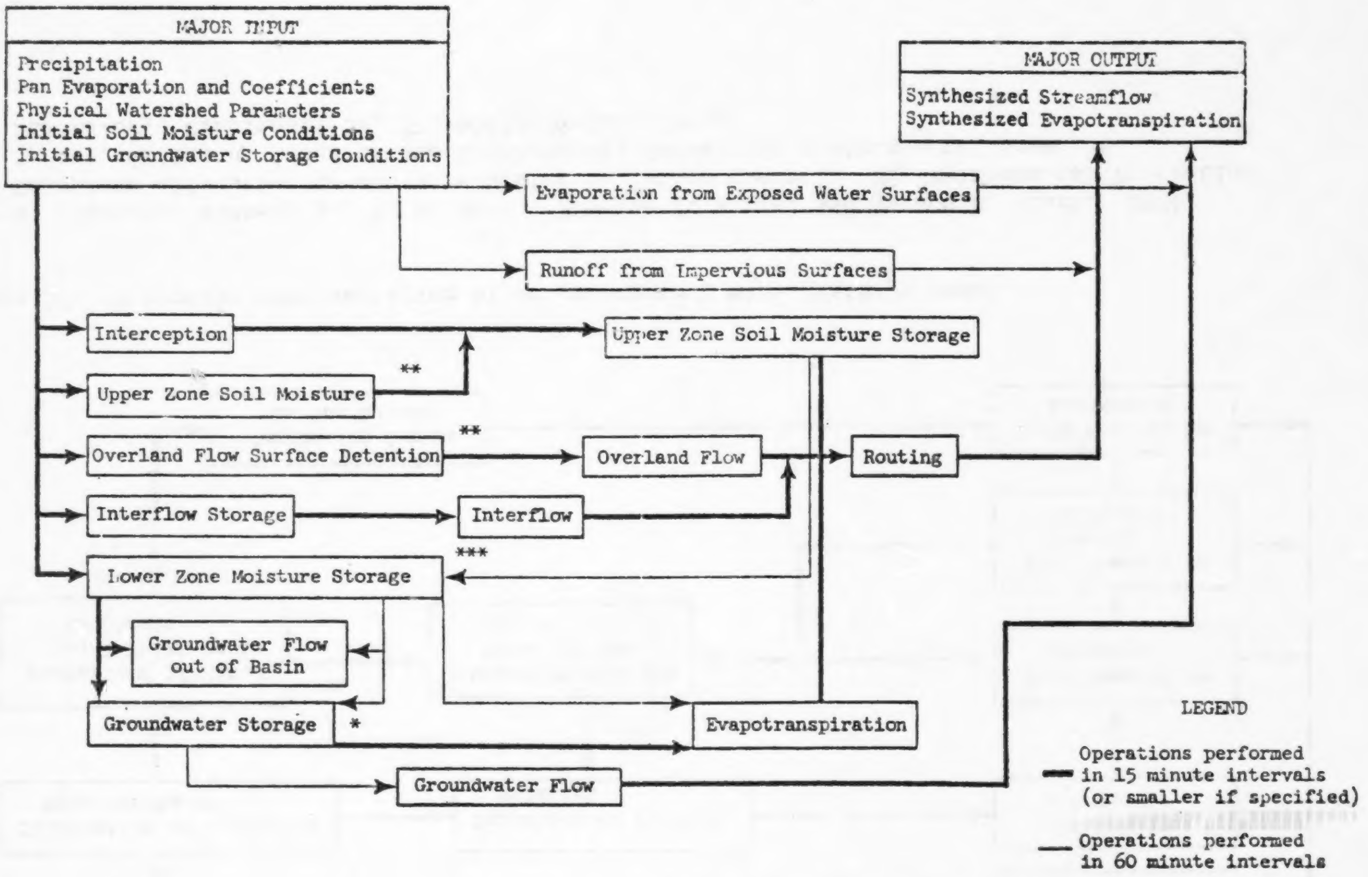

MAJOR INPUT
Precipitation
Pan Evaporation and Coefficients
Physical Watershed Parameters
Initial Soil Moisture Conditions
Initial Groundwater Storage Conditions
MAJOR OUTPUT
Synthesized Streamflow
Synthesized Evapotranspiration
Evaporation from Exposed Water Surfaces
Runoff from Impervious Surfaces
Interception
Upper Zone Soil Moisture Storage
Upper Zone Soil Moisture
**
Overland Flow Surface Detention
**
Overland Flow
Routing
Interflow Storage
Interflow
***
Lower Zone Moisture Storage
Groundwater Flow out of Basin
Groundwater Storage
*
Evapotranspiration
Groundwater Flow
LEGEND
Operations performed in 15 minute intervals (or smaller if specified)
Operations performed in 60 minute intervals

Figure 56. Moisture accounting in the Stanford Watershed Model (SWM).

Source: Shumate, Kenesaw S., E. E. Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112, 476 p.

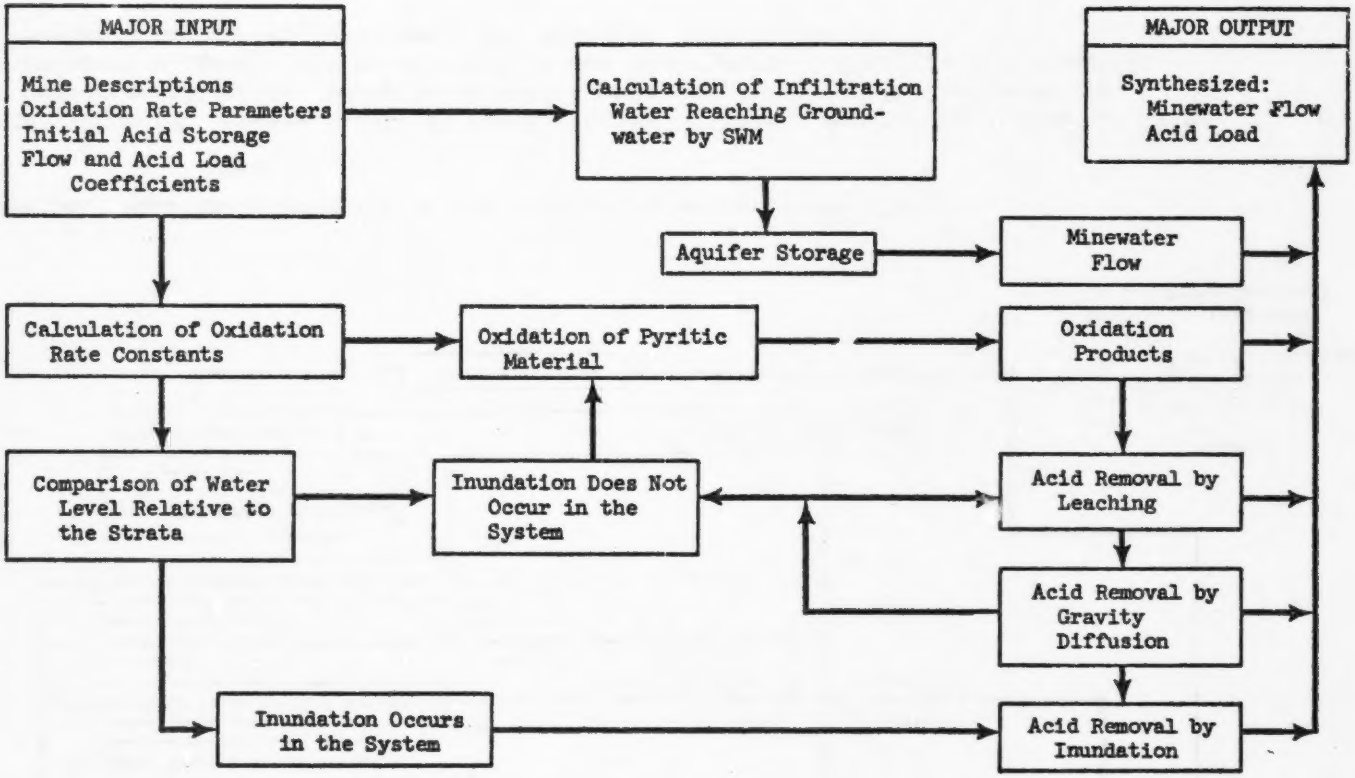

MAJOR INPUT
Mine Descriptions
Oxidation Rate Parameters
Initial Acid Storage
Flow and Acid Load Coefficients
Calculation of Infiltration Water Reaching Groundwater by SWM
MAJOR OUTPUT
Synthesized:
Minewater Flow
Acid Load
Aquifer Storage
Minewater Flow
Calculation of Oxidation Rate Constants
Oxidation of Pyritic Material
Oxidation Products
Comparison of Water Level Relative to the Strata
Inundation Does Not Occur in the System
Acid Removal by Leaching
Acid Removal by Gravity Diffusion
Inundation Occurs in the System
Acid Removal by Inundation

Figure 57. Schematic representation of an underground mine drainage model.

Source: Shumate, Kenesaw S., E. E. Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112, 476 p.

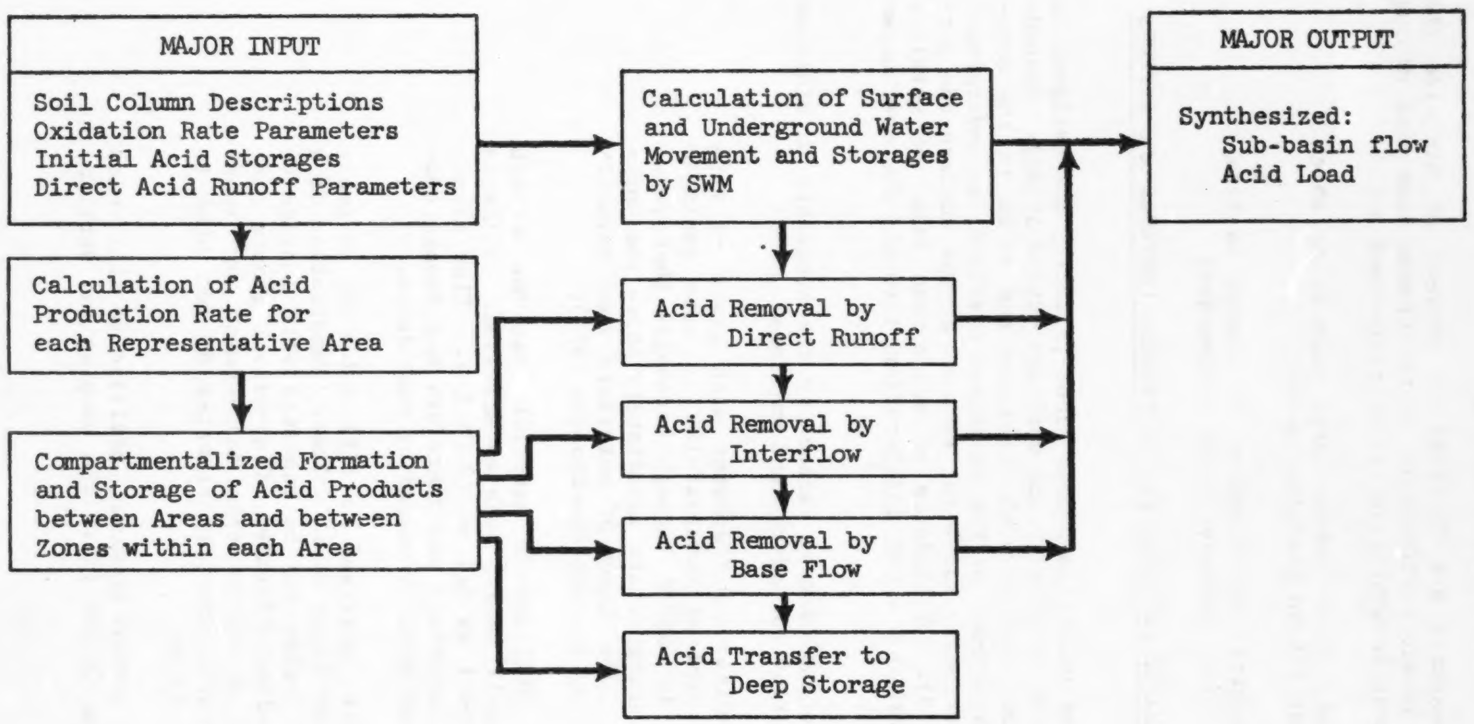

MAJOR INPUT
Soil Column Descriptions
Oxidation Rate Parameters
Initial Acid Storages
Direct Acid Runoff Parameters
Calculation of Acid Production Rate for each Representative Area
Compartmentalized Formation and Storage of Acid Products between Areas and between Zones within each Area
Calculation of Surface and Underground Water Movement and Storages by SWM
Acid Removal by Direct Runoff
Acid Removal by Interflow
Acid Removal by Base Flow
Acid Transfer to Deep Storage
MAJOR OUTPUT
Synthesized:
Sub-basin flow
Acid Load

Figure 58. Schematic representation of a coal refuse pile drainage model.

Source: Shumate, Kenesaw S., E. E., Smith, Vincent T. Ricca, and Gordon M. Clark. 1976. Resources allocation to optimize pollution control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112, 476 p.

3.0. POLLUTION CONTROL

Pollution control measures are designed to prevent or minimize the potentially adverse environmental effects of waste streams from coal mining activity. Pollution control technologies are characterized as:

- In-process controls which reduce waste volumes or which moderate waste composition characteristics
- End-of-process controls which render the wastes as harmless as possible before release to the environment

3.1. STANDARDS OF PERFORMANCE TECHNOLOGY: IN-PROCESS CONTROLS AND EFFECTS ON WASTE STREAMS

In-process controls at underground coal mines primarily are designed to minimize the influx of water to underground workings (USEPA 1976c). Groundwater enters an underground mine through fractures and voids in the overburden and coal seam. Disturbance of the landscape overlying an underground mine may increase the opportunity for water to pond at the surface and percolate downward (Figure 59). Subsidence of overburden into the workings also can increase the rate of water infiltration through the overburden (Section 2.1.1.2.1.).

Three kinds of in-process control technology are available to minimize the rate of water infiltration to underground workings:

- Sealing of boreholes and fractures with grout -- this technique can be applied successfully in some geologic materials. Grout is pumped through boreholes that penetrate the water-bearing strata immediately above the workings (Figure 60). The types of materials that normally are used for grouting include (Loofbourow 1973):

  -- Clay grouts: utilized in material that has a high total volume of small voids, such as alluvium. Fillable voids may be as small as 0.1 mm (0.04 in). Clay grouts bond with natural materials and therefore may remain competent during ground motions caused by subsidence.

  -- Cement slurries: utilized to fill voids of variable size and moderate or large total volume. Penetration of a cement slurry into voids may be enhanced with lubricants such as clay or sodium silicate. Clay-cement grouts generally have lower strengths than sand-cement and sand-cement-fly ash grouts; non-clay slurries do not bind to natural (in situ) clays.

  -- Acrylamides and chrome lignins: utilized to fill voids as small as 0.01 mm (0.004 in). The pumping and settling

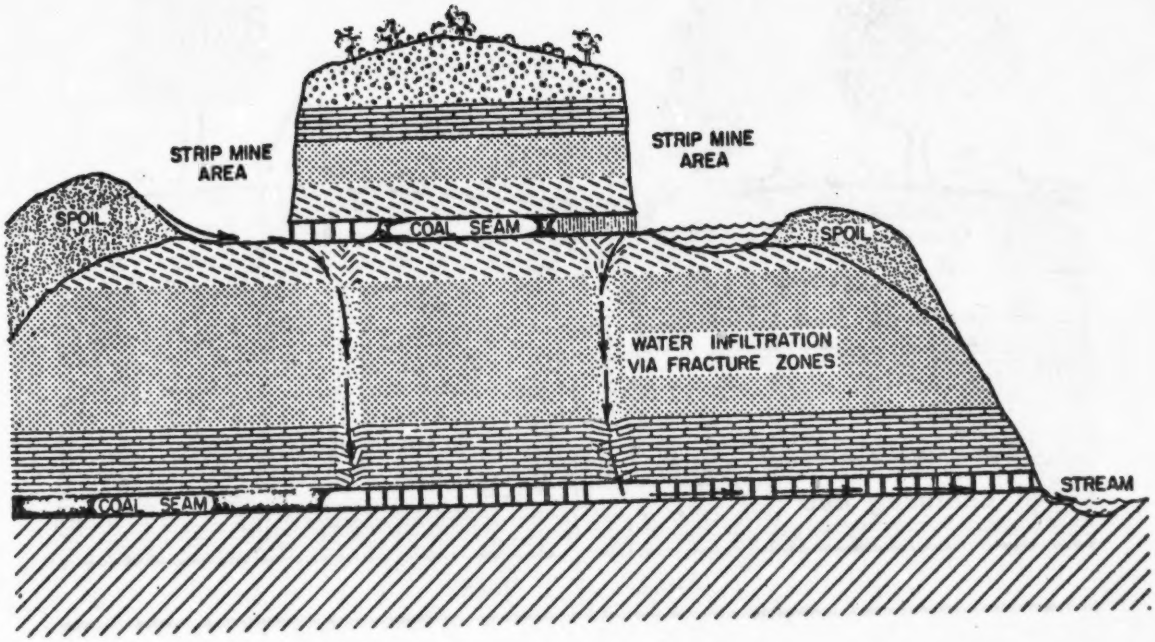

STRIP MINE AREA
STRIP MINE AREA
SPOIL
COAL SEAM
SPOIL
WATER INFILTRATION VIA FRACTURE ZONES
COAL SEAM
STREAM

Figure 59. Infiltration of water to an underground mine through disturbed overburden.

Source: US Environmental Protection Agency. 1976. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Materials, Washington DC, EPA-440/1-76/057-a, 288 p.

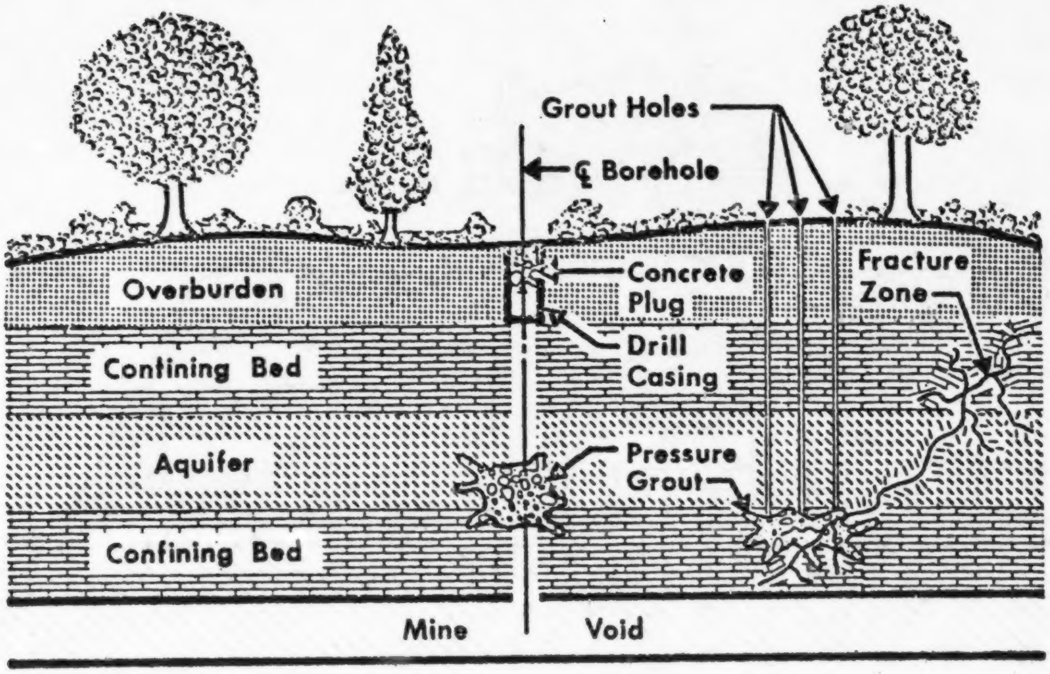

Grout Holes
℄ Borehole
Overburden
Concrete Plug
Drill Casing
Fracture Zone
Confining Bed
Aquifer
Pressure Grout
Confining Bed
Mine
Void

Figure 60. Sealing of boreholes and fractures to control infiltration of groundwater to an underground coal mine.

Source: US Environmental Protection Agency. 1976. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Materials, Washington DC, EPA-440/1-76-057-a, 288 p.

characteristics of these materials can be controlled through the use of admixtures.

-- Resorcinol formaldehydes: utilized to fill voids larger than 0.01 mm (0.004 in). These materials have a low viscosity and short setting time, and can be used to fill shrinkage cracks in cement slurry grouts.

- Dewatering of overlying materials -- The volume of water that enters underground workings can be reduced by dewatering the overlying strata with shallow, pumped wells. This technology has been demonstrated at hematite mines near Iron River, Michigan (Loofbourow 1973). Figure 61 illustrates a hypothetical configuration of wells for dewatering an underground coal mine.

- Temporary control of subsidence -- The absolute control or prediction of subsidence is not feasible in underground coal mining (Cummins and Given 1973). A structure is protected against subsidence by assuming an angle of draw equal to 15° with the limbs of the angle intersecting the surface approximately 4.5 m (15 ft) outside the foundation line. The extraction ratio is held at 50% for portions of the coal seam that lie outside the limbs of the angle of draw (Figure 62).

  Surface water from runoff at underground coal mines and coal cleaning facilities can be controlled using established techniques for site drainage (Grim and Hill 1974, USEPA 1976b). These techniques employ diversions, filter strips with a suitable vegetation, and the stabilization of exposed spoils and wastes to minimize the contamination of runoff with pollutants.

In-process controls for coal cleaning operations generally are limited to process water recycling measures (where applicable) and runoff return conveyances from impervious areas which may feed stormwater to storage facilities for process water makeup or to settling basins (if necessary) for treatment prior to discharge (USEPA 1976c).

3.2. STANDARDS OF PERFORMANCE TECHNOLOGY: END-OF-PROCESS CONTROLS AND EFFECTS ON WASTE STREAMS (EFFLUENTS)

Mine water, acid mine drainage, and effluents emanating from coal mines, coal preparation facilities, coal storage piles, and refuse piles require treatment to remove or neutralize objectionable constituents. Treatment systems for these waste streams range from simple detention basins to relatively complex chemical treatment plants. The treatment systems described below are summarized in the USEPA development document for new

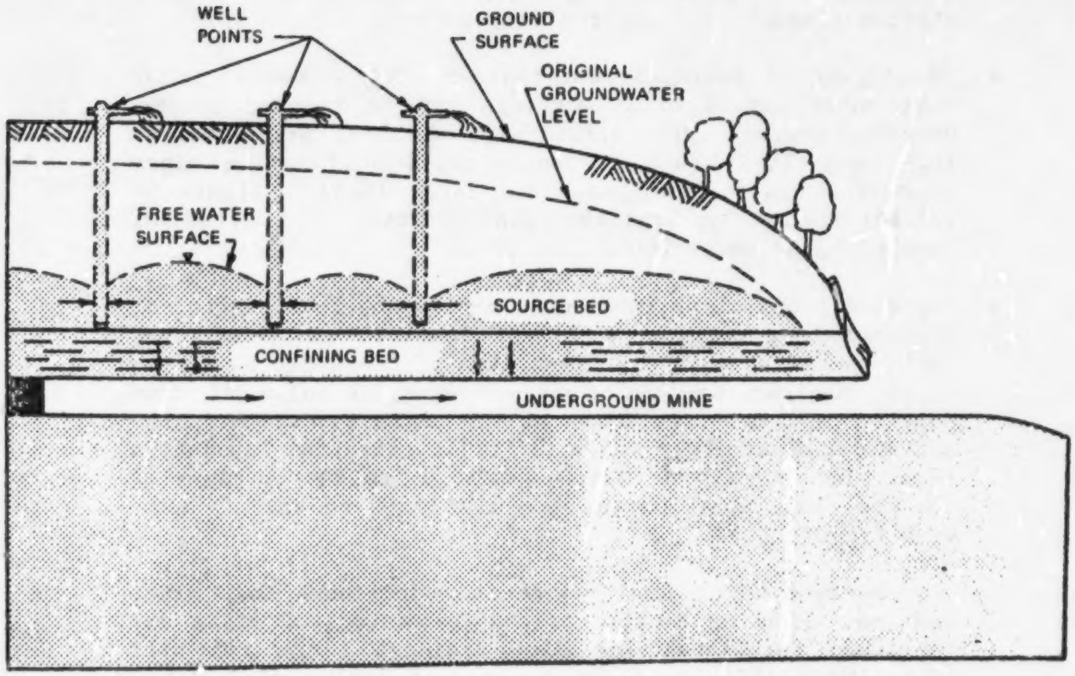

WELL POINTS
GROUND SURFACE
ORIGINAL GROUNDWATER LEVEL
FREE WATER SURFACE
SOURCE BED
CONFINING BED
UNDERGROUND MINE

Figure 61. Hypothetical configuration of pumped wells for dewatering of pumped wells for dewatering the strata that overly an underground coal mine.

Source: Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for the US Environmental Protection Agency National Environmental Research Center, Las Vegas NV, 84 p.

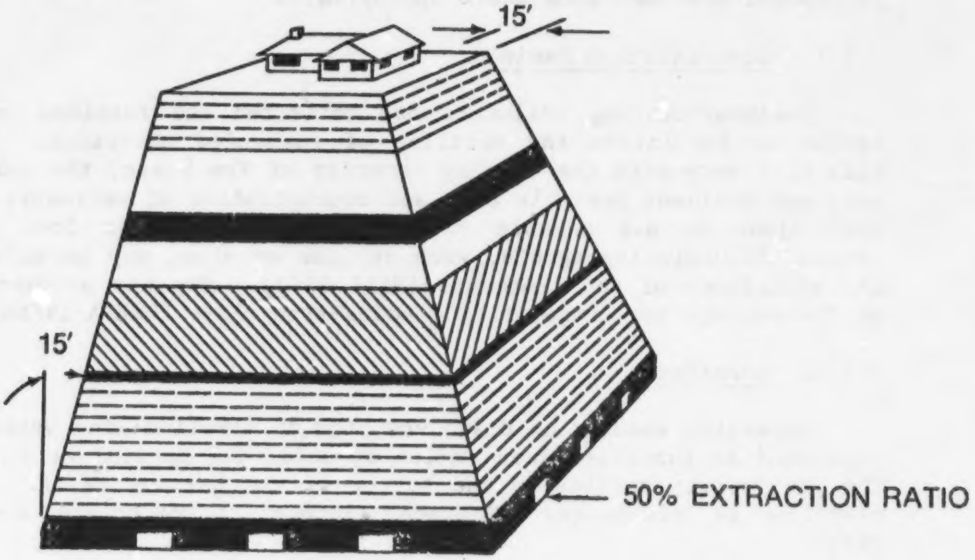


Figure 62. Commonly used method for temporary protection of structures from subsidence.

Source: Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, 455 p.

source coal mining activities (USEPA 1976c). Citations to corroborative literature are indicated where appropriate.

3.2.1. Sedimentation Basins

Sediment-bearing effluents are collected and retained in one or more basins to facilitate the settling of suspended materials. The retention time will vary with the holding capacity of the basin, the volume of influent, and dominant particle size and concentration of sediments. When retention alone is not capable of reducing the sediment load to acceptable levels, flocculating agents, such as lime or alum, may be added to increase the efficiency of the treatment (Hill 1973). Organic polymers may be used as flocculants for coagulating alumina-type clays (USEPA 1976c).

3.2.2. Aeration

Excessive amounts of dissolved iron in alkaline mine waters can be precipitated as insoluble iron oxides by utilizing natural or forced aeration. The precipitate settles to the bottom of the holding basin. The clarified overflow is discharged (National Industrial Pollution Control Council 1971).

3.2.3. Neutralization

Neutralization is the most commonly used method for treating acid mine drainage and removing heavy metals. Neutralization systems are individually designed on the basis of the selected alkaline reagents, the quality and flow of feed water, and the site-related considerations. Typical systems include the addition of the alkaline reagent to feed water; mixing; aeration; and removal of the precipitate. The general advantages and disadvantages of neutralization treatment processes are listed below.

Advantages:

- Neutralization removes acidity and adds alkalinity.
- Neutralization raises pH.
- The concentrations of heavy metals are reduced. Most heavy metals will precipate as pH increases. Concentrations of metals such as copper, zinc, managanese, nickel, aluminum, and cobalt can be reduced to less than 0.5 mg/l (Hill 1973).
- In highly acidic acid mine drainage, sulfate can be removed if sufficient calcium ions are added to cause the precipitation of calcium sulfate (Grim and Hill 1974).

Disadvantages:

- Hardness is not reduced and may be increased.
- The concentration of sulfate remains high.
- Iron usually is not reduced to less than 3 to 7 mg/l (Grim and Hill 1974), although reductions to less than 0.5 mg/l have been reported (Hill 1973).
- A waste sludge is produced which requires disposal.

Several alkaline reagents are available for the neutralization of mine water, including calcium carbonate (high calcium limestone), calcium oxide (calcinated, quick, or pebble lime), calcium hydroxide (hydrated lime), calcium carbonate-magnesium carbonate (dolomite or dolomitic limestone), calcium oxide-magnesium oxide (burnt or calcined dolomite), calcium hydroxide-magnesium hydroxide (pressure hydrated dolomite), calcium hydroxide-magnesium oxide (hydrated dolomite or partially hydrated dolomite), sodium carbonate (soda ash), sodium hydroxide (caustic soda), and anhydrous ammonia (Lovell 1973).

The selection of the alkaline reagent should be based upon the chemical characteristics and volume of drainage water, the treatment plant location, and the performance potentials of the various reagents as determined by theoretical stoichiometries of anticipated neutralization reactions. Factors that also should be considered in selecting a reagent include reagent availability, transportation, cost, reactivity, and chemical and physical characteristics of the impure sludges (Lovell 1973). Caustic soda, for example, may be desirable on the basis of anticipated process stoichiometries or ease of procurement locally, but has the disadvantage of being dangerous to handle.

Limestone is the cheapest alkaline reagent and produces a smaller quantity of denser sludges than lime, which is the most commonly used reagent. Except for dolomite, however, limestone has the lowest reactivity rate of the agents used for neutralization. Limestone is not effective for treatment of waters above pH 6.5. Limestone also is ineffective in highly ferrous iron water, which usually requires a more complex treatment system. The particle size, characteristics, and method of application of the limestone are critical to performance (Grim and Hill 1974).

Hydrated and calcined lime are similar in their performance and react rapidly with coal mine drainage (Lovell 1973). When properly reacted and controlled, nearly perfect reagent utilizaton efficiency is possible. The control of reagent addition, however, becomes more difficult as the acidity of the water increases. These reagents usually form a voluminous, low-density sludge that gels upon aging. This sludge has poor handling and dewatering characteristics.

For large treatment facilities, a two-stage system utilizing limestone and lime may offer the advantages of both reagents (Hill 1973). Limestone, effective at low pH, is added first to the AMD to increase the pH to 4.0 to 4.5. The second stage uses lime to raise the pH to a desirable level. This combined system offers the advantages of improved cost, more desirable sludge characteristics, a high quality final effluent, and the ability to treat ferrous iron AMD (Grim and Hill 1974).

Dolomite reagents perform similarly to reagents with high calcium contents, although they generally are more costly and less available (Lovell 1973). The volume and characteristics of the treatment sludge also are comparable, except for the treatment of highly polluted water. The precipitation rate of calcium sulfate during treatment is controllable, but the treated effluent may not meet USEPA effluent limitations. Because of its hardness, dolomite is the least reactive reagent, and its application is limited to lightly mineralized waters. Effluents from treatment systems utilizing dolomite reagents may have higher than desired concentrations of magnesium (Lovell 1973).

Sodium hydroxide (caustic soda) treatment of mine discharge is most desirable as an emergency or temporary measure to prevent the discharge of waters of unacceptable quality. Sodium hydroxide is more costly than limestone or lime and is dangerous to handle. Control of pH during the treatment process is difficult because of the fast reaction rate. The sludge produced by sodium hydroxide treatment may be less dense than sludge produced with lime and may contain less calcium sulfate (Lovell 1973). Sodium hydroxide systems for control of small flows are uncomplicated, do not require electricity, and are easily moved for fast, temporary treatment.

Sodium carbonate (soda ash), like caustic soda, is very reactive but expensive and difficult to control. The sludge produced by a sodium carbonate treatment system is denser than sludge produced by lime or caustic soda systems, and is less inclined to gel (Lovell 1973). Use of sodium carbonate, however, greatly increases the concentration of dissolved solids in the final effluent. Sodium carbonate treatment systems can be packaged as simple feeders that are easily transported for temporary application. The reagent, however, is dangerous to handle.

Anhydrous ammonia also may be used to neutralize mine waters. An anhydrous ammonia system is inexpensive and simple to operate and maintain. The disadvantages of this reagent, however, are numerous and generally preclude its use except in extraordinary situations. These disadvantages include greater reagent costs than for lime or limestone, larger sludge volume, ammonia loss to the atmosphere by diffusion or by air-stripping where aeration is practiced, and high levels of ammonia and nitrate in ammonia-neutralized mine drainage.

Discharge of ammonia-treated effluent may produce adverse effects on receiving streams caused by the toxicity of ammonia to fish and other aquatic organisms, the depression of dissolved oxygen concentrations through nitrification, and nitrate enrichment of water which may lead to eutrophication (Grim and Hill 1974). This reagent is best applied to treat small flows of mine water where the treated effluent is used to irrigate spoil banks, producing no runoff to receiving waters. In this situation there is no damage to receiving waters and the reclamation of spoil and refuse banks is enhanced through the benefit of the water and nitrogen supplied by the treated effluent to the vegetation.

3.2.4. Reverse Osmosis and Neutrolysis

Reverse osmosis is a concentrating process in which the pollutants are retained on one side of a membrane that is permeable to water. This process separates inorganic ions and dissolved and suspended solids in solution. All heavy metals are reduced by more than 99%. The efficiencies for removal of chemical constituents in coal mine drainage are listed in Table 34. Calcium sulfate usually is the first material to precipitate from mine drainage. Water recoveries of up to 90% may be obtained, although recovery is limited by the precipitation of materials on the membrane (Hill 1973). This process currently is favored over ion exchange because of its greater efficiency and added ability to remove organics (Monti and Silbermann 1974, in Wachter and Blackwood 1978). In application for treatment of acid mine drainage, however, the disposal of the waste stream generated by reverse osmosis is a major problem. To reduce this problem, a neutrolysis system may be employed whereby the waste stream is neutralized, the sludge is removed, and the neutralized water is returned as influent to the reverse osmosis unit. This system provides water recoveries in excess of 99% (Hill and others 1971, in Hill 1973).

3.2.5. Ion Exchange

Ion exchange is a sorption process in which ions attached to an exchange medium are replaced by ions passing through the medium in solution. Removal efficiencies generally are 97% for total phosphate, 90% for nitrates, 100% for sulfates, and 45% for COD (Weber 1972, in Wachter and Blackwood 1978). Problems encountered in ion exchange treatment include resin fouling, interference by certain ions, limited loading capacity, prohibitive operating costs, and disposal of regenerating solutions (Hill 1973). Two ion exchange processes are in use (USEPA 1976c):

- Sul-biSul process removes cations with one or more resins. Carbon dioxide then is removed by decarbonization; sulfates and hydrogen ions are removed by a strong-base anion resin. The effluent is filtered before discharge.

- Modified desal process removes sulfate and other anions from influent water using a weak-base anion resin. The water then is aerated to remove carbon dioxide and to oxidize ferrous iron species. Hydroxides of metals then are precipitated with lime; suspended solids are removed;

Table 34. Efficiency of mine drainage treatment by reverse osmosis.

	Percent Removal
Ca	98.0 - 99.8
Mg	98.5 - 99.8
Fe, Total	98.5 - 99.9
Al	91.7 - 99.2
Mn	97.8 - 99.1
Cu	98.7 - 99.5
SO_4	99.3 - 99.9
Acidity	81.0 - 91.7
Specific Conductance	95.0 - 99.9

Source: Hill, Ronald D. 1973. Water pollution from coal mines. Paper presented at the 45th annual conference, Water Pollution Control Association of Pennsylvania, University Park PA. United States Environmental Protection Agency, National Environmental Research Center, Cincinnati OH, 11 p.

and the effluent is filtered before discharge to potable water supplies.

3.2.6. Biochemical Oxidation of Ferrous Iron

To permit the effective use of limestone neutralization and thus realize its advantages of low cost and minimal sludge production, oxidation of waters with high ferrous content (greater than 100 mg/l) should precede neutralization (Lovell 1973). Oxidation by air at low pH is impractically slow, however, and the need for stronger chemical oxidants increases treatment costs, thus eliminating one of the advantages of limestone. Biochemical oxidation utilizing autotrophic or chemolithotrophic bacteria therefore becomes advantageous by reducing treatment costs. Bacteria such as *Ferrobacillus ferrooxidans* and *Ferrobacillus thiooxidans* can oxidize soluble ferrous iron in an acid solution. The mine water is introduced to the bacteria through a trickling filter-type unit. Oxidation rates on the order of thousands of mg/l/hr may be obtained by this method (Lovell 1973).

3.3. STANDARDS OF PERFORMANCE TECHNOLOGY: END-OF-PROCESS CONTROLS AND EFFECTS ON WASTE STREAMS (EMISSIONS)

Control features for coal preparation plants include structural and operational components that are applied singly or in combinations at various plant emission points (Table 35). These control features include:

- Cyclone -- uses centrifugal force to separate fine particles from hot gases as they enter the vessel tangentially (Figure 63). Dust-laden gases form an outer vortex of dirty gas as dust particles strike the cylinder wall and spiral downward to a collector. Clean gases spiral upward in an inner vortex and exit through an outlet (King and Fullerton 1968). The dust collection efficiency, capacity, and other operating characteristics of cyclones vary with diameter of the brick-lined or water-jacketed vortex chamber (Table 36).

- Scrubber -- uses small droplets of water to agglomerate dust, which then flows from the vessel. Scrubber types are differentiated on the basis of dust agglomeration methods that result in different water consumption rates per measure of dust-laden gas (Table 37). Four basic scrubber types are recognized (USEPA 1977b):

  -- Impingement: stream of hot gases impinges the surface of a water reservoir, causing dust to agglomerate in a turbulent mixture of gas and water bubbles (King and Fullerton 1968)

  -- Centrifugal (wet cyclones): stream of water is sprayed at high velocity across the dust-laden influent, causing

Table 35. Applications of emission control technologies for materials handling and coal cleaning operations.

Emission Source	Control Technology Cyclone	Scrubber	Spray	Filter	Enclosure
Materials Handling					
Car dumps		X	X		X
Truck dumps		X	X		X
Bins, silos				X	
Breakers, crushers			X	X	X
Conveyor transfer			X	X	X
Screens				X	X
Transport loading	X			X	X
Coal Cleaning					
Surge bin				X	X
Thermal dryer stack	X	X			
Vibrating screens				X	X
Air tables	X			X	X
Crusher			X	X	X

Source: US Environmental Protection Agency. 1977b. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

Table 36. Operating characteristics of dust-collecting cyclones.

	Minimum	Maximum
Cyclone diameter (cm)	5.1	549
Capacity (cmm)	0.33	700
Inlet velocity (mps)	4.6	22.9
Pressure drop (cm)	1.3	15.2
Smallest size collected at 50% efficiency (μ)	10	200

Source: US Environmental Protection Agency. 1977b. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

Table 37. Operating characteristics of scrubbers for dust control.

Scrubber type	Water Consumption (1pm/1,000 cmm gas)	Pressure Drop (cm)	Capacity (cmm)	Maximum Efficiency % Particle Size Range (μ)
Impingement	6.7 - 11.3	15.2 - 20.3	2,520	95 1-5
Centrifugal	9.0 - 22.5	5.1 - 15.2	3,920	90 2-5
Dynamic	2.3	2.5	700	95[a] 2-5
Venturi	6.8 - 33.8	30.5 - 152.4	3,920	98 <1

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[a] Estimated.

Source: US Environmental Protection Agency. 1977b. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

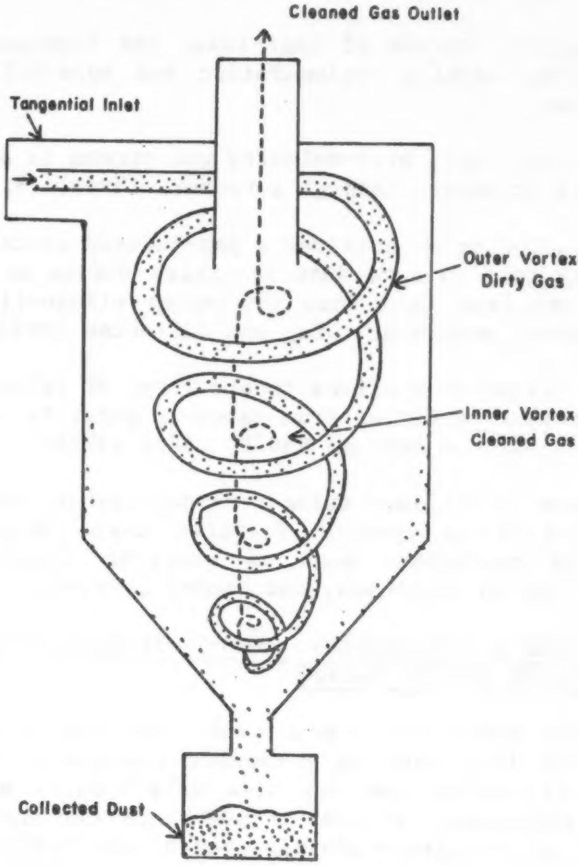

Cleaned Gas Outlet
Tangential Inlet
Outer Vortex-
Dirty Gas
Inner Vortex-
Cleaned Gas
Collected Dust

Figure 63. Cyclone separator for dust collection.

Source: Leonard, Joseph W., and David R. Mitchell. 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. New York NY, 926 p.

agglomeration and separation of dust from gas using the same principles described for dry cyclones

-- Dynamic: stream of dust-laden gas impinges a wetted fan blade, causing agglomeration and separation of dust particles

-- Venturi: hot, high-velocity gas stream is sprayed with water as it passes through a Venturi throat (Figure 64)

- Spray collector -- utilizes a gas-induced curtain of water droplets that capture dust particles during both acceleration and free fall into the spray elimination zone or entrainment separator (King and Fullerton 1968).
- Fabric filter -- utilizes finely woven or felted fabric to capture dust particles from gases at moderate temperatures (70° to 340°C or 160° to 650°F; USEPA 1977b).
- Enclosure -- utilizes structural devices at critical emission points to contain fugitive dusts from material-handling operations such as conveyor transfer, filter separation in baghouses, and hopper loading.

3.4. STATE-OF-THE-ART TECHNOLOGY: END-OF-PROCESS CONTROLS AND EFFECTS ON WASTE STREAMS (SOLID WASTES)

Coal refuse dumps and impoundments for coal refuse slurry are constructed for the long term or permanent storage of coarse and fine coal refuse. The techniques used for site selection, construction, operation, and permanent maintenance of coal refuse dumps and impoundments are the subjects of regulatory programs administered by the USOSM (Section 1.6.3.). In the sections that follow, guidelines for the utilization of coal refuse dumps and impoundments are described first, followed by mine waste treatment techniques.

3.4.1. Guidelines for coal refuse dumps and impoundments

The following guidelines are based in part on the results of a study performed by the USEPA Industrial Environmental Research Laboratory at Cincinnati, Ohio (W. A. Wahler and Associates 1978):

- Site selection

  -- Refuse disposal sites should isolate the wastes from groundwater and surface waters.

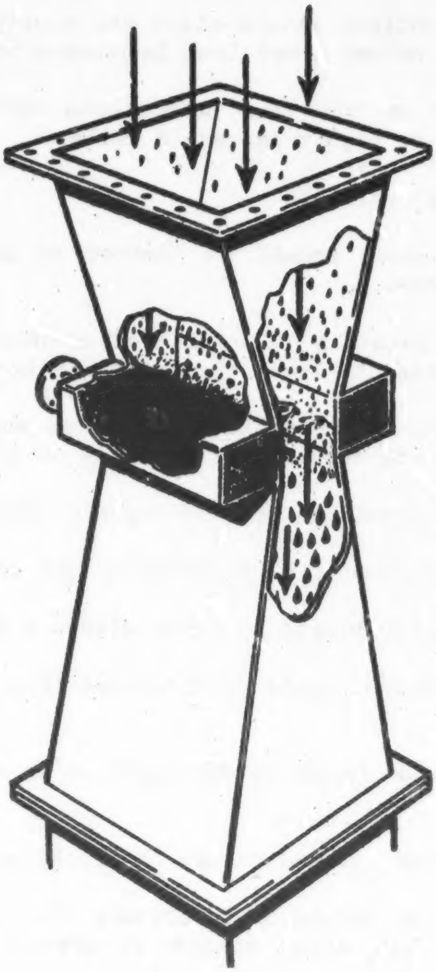


Figure 64. Venturi scrubber for dust separation.

Source: Leonard, Joseph W., and David R. Mitchell. 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. New York NY, 926 p.

-- Sites should be inherently stable. Certain terrain features in mountainous areas of Appalachia are known to be unstable (Figure 65).

-- Site configurations should allow the routing of drainage from coarse refuse dumps into impoundments.

-- Sites should be free from underground workings, limestone channels, or highly permeable soils.

- Construction and operation

  -- Site disturbances should be limited to the immediate area of operations.

  -- Clearing or grubbing of a site in advance of dumping should be minimized to limit the extent of exposed soils.

  -- Coarse and fine refuse should be mixed where practicable to enhance the mechanical stability of the dump.

  -- Refuse dumps should be free of organic debris.

  -- Surface waters should be diverted around refuse dumps.

  -- Refuse should be placed in cells within a dump.

  -- Valley-fill dumps should be developed from the heads of valleys.

  -- Side-hill dumps should be developed in perimeter strips.

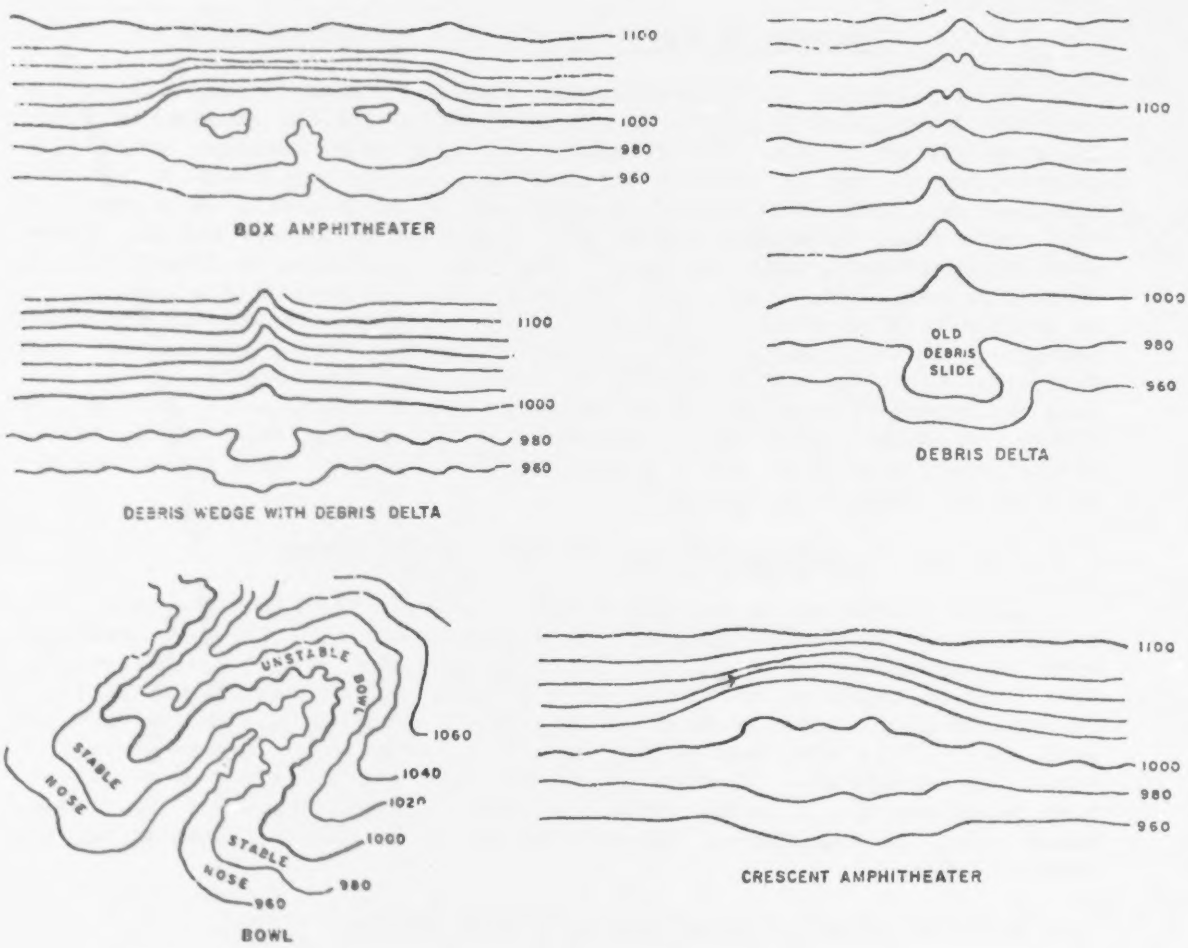
  -- Surface area of exposed refuse should be minimized.

  -- Active surfaces should be relatively flat (thus minimizing erosion), but steep enough to prevent ponding of water.

  -- Refuse should be placed using methods that minimize the segregation of fine- and coarse-sized materials.

  -- Noncritical portions of the dump should be reserved for placement of refuse during inclement weather.

Underground coal mines historically have been employed for the disposal of coal refuse. This practice now is regulated by the USOSM and is subject to performance standards established under the SMCRA (Section 1.6.3.).


1100
1000
980
960
1100
1000
OLD DEBRIS SLIDE
980
960
1100
1000
980
960
UNSTABLE BOWL
STABLE NOSE
1060
1040
1020
1000
STABLE NOSE
980
960
1100
1000
980
960

BOX AMPHITHEATER

DEBRIS DELTA

DEBRIS WEDGE WITH DEBRIS DELTA

BOWL

CRESCENT AMPHITHEATER

Figure 65. Schematic topographic diagrams of five landforms that are highly susceptible to landslides.

Source: Lessing, Peter, B. R. Kulander, B. D. Wilson, S. L. Dean, and S. M. Wooding. 1976. West Virginia landslides and slide-prone areas. West Virginia Environmental Geology Bulletin 15, 20 maps (scale 1:24,000).

3.4.2. Mine Waste Treatment Techniques

Three techniques for treating or stabilizing mine waste are described below.

3.4.2.1. Treatment of Mine Waste with Neutralization Sludge

The application of neutralization sludge to mine wastes offers the potential benefits of providing a practical outlet for the disposal of residuals generated by the neutralization of acid mine drainage while also contributing to the reclamation of mine wastes. The applicability of this treatment has been demonstrated by Grube and Wilmoth (1975) in a study in which mine waste materials planted with a mixture of fescue and red clover were spray irrigated with the slurry from lime, limestone, or lime/limestone neutralization. This study indicated that spray irrigation of sludge should be applied only in areas of relatively flat topography to prevent the undesirable erosion of sludge which occurred readily during medium and high intensity rainfalls. The sludge-treated areas had significantly cooler surface soil temperatures and dried out more slowly than spoil lacking the sludge, provided runoff of acceptable quality during mild precipitation events, and appeared to have a slight beneficial effect upon the establishment and maintenance of vegetation.

3.4.2.2. Treatment of Mine Waste with Sewage Sludge

Sewage sludge may be applied to mine wastes to supply nutrients for the establishment and growth of plant cover (Grim and Hill 1974). Treatment with sewage sludge is applicable to both acid and alkaline mine wastes. This form of treatment increases water-holding and ion exchange capacities of mine wastes, creates a more favorable root zone for plants, buffers the extremes of pH in mine wastes, and immobilizes ions which may be present in toxic concentrations. Species of plants that are tolerant to relatively high concentrations of metals should be used for revegetation of the treated waste pile, if significant concentrations of metals are present in the sewage sludge.

3.4.2.3. Chemical Stabilization of Mine Wastes

Chemical stabilization involves the mixing of a reagent with mine wastes or refuse to form a weather-resistant layer that effectively prevents erosion by wind or water. Chemically stabilized wastes seldom are intended to be permanent, and they are not so durable or desirable as restoration of soil material and revegetation. Chemical stabilizers have useful applications, however, for the temporary control of erosion on dry sections of active refuse ponds, sites unsuited for the growth of vegetation, or in areas where soil-covering material is not available.

4.0. OTHER CONTROLLABLE IMPACTS

4.1. AESTHETICS

New source mining activity may involve large and complex operations occupying hundreds of acres. Coal storage and handling areas, haul roads, spoil and refuse piles, exposed soils, dust, erosion, and sediment-laden streams are aesthetically displeasing to many. Particularly in non-industrial rural and suburban areas, mining activity can represent a noticeable intrusion on the landscape. Measures to minimize the impact on the environment must be developed during site selection, mine planning design, and reclamation. The applicant should consider the following factors where feasible to reduce potential aesthetic impacts.

- Existing nature of the area -- The topography and major land uses in the area of the candidate sites for surface facilities are important. Topographic features, such as hills, can be used to screen the operation from view. A lack of topographic relief will require other means of minimizing impact, such as regrading or vegetation buffers.

- Proximity of operations to parks and other areas where people congregate for recreation and other activities -- The location of public use areas should be mapped and presented in the EID. Representative views of the mining site from observation points should be described using maps and photographs. The visual effects on these recreational areas should be considered in the EID in order to develop the appropriate mitigation measures.

- Transportation System -- The visual impact of new access roads, rail lines, haul roads, and refuse piles on the landscape should be considered. Locations, construction methods and materials, and maintenance should be specified.

4.2. NOISE AND VIBRATION

The major sources of noise associated with coal mining activities include:

- Coal transportation systems (railroads and haul roads)
- Coal preparation facilities (crushers and screens)
- Blasting operations
- Land reclamation/grading equipment

Mining activities can create significant ambient noise levels. Noise in some situations can be attenuated effectively with thick stands of vegetation or other barriers. At distances of 450 tp 600 m (1,500 to 2,000 ft) from coal mining equipment, noise levels may decrease by 20 dBA from those measured 15 m (50 ft) from the source. Even at such distances, however, the increases in noise levels due to coal mining activities still may be noticeable. Noise receptors within 1 km (0.5 mi) of the source are the most affected and should be documented in the EID.

Noise also can create serious health hazards for exposed workers. USEPA has recommended a 75-dBA, 8-hour exposure level to protect workers from loss of hearing, and a 55-dBA background exposure level to protect adjacent areas from annoyance of outdoor activity. Control methods to minimize noise include:

- Mufflers on equipment
- Lined ducts
- Partial barriers
- Vibration insulation
- Imposed speed limits on vehicles
- Scheduled equipment operations and maintenance

To evaluate the noise generated from proposed underground coal mines and coal cleaning facilities, the following considerations should be addressed:

- Identify all noise-sensitive land uses and activities adjoining the proposed site of operations

- Measure the existing ambient noise levels of the areas adjoining the proposed site

- Identify existing noise sources, such as traffic, aircraft flyover, and other industry in the general area

- Identify the State or local noise regulations that apply to the site

- Calculate the noise levels of proposed mining and cleaning operations and compare those values with the existing area noise levels and the applicable noise regulations

- Assess the impact of noise from the proposed operations and determine noise abatement measures to minimize noise levels (quieter equipment, noise barriers, improved maintenance schedules, etc.)

4.3. ENERGY SUPPLY

The impact of coal mining activity on local energy supplies depends largely on the type of mine operation proposed and the extent of ancillary facilities. Two criteria commonly are used to assess the efficiency of various mining methods:

- Percentage of in-place coal recovered
- Amount of energy required including expenditures of diesel fuel and electricity to operate all mining equipment (University of Oklahoma 1975)

The permit applicant should evaluate the energy efficiencies and demands of all methods considered during project planning in the context of an alternatives analysis. Feasible design modifications should be considered in order to reduce energy needs.

At a minimum, the applicant should provide the following information in the EID:

- Total demand of energy from external sources required for proposed operations
- Total energy generated at the site of operations
- Energy requirements by type
- Sources of energy off-site
- Proposed measures to conserve or reduce energy demand and to increase the operating efficiency of underground coal mining and coal cleaning equipment
- Energy expected to be produced
- Energy expected to be rendered unavailable using current technology.

4.4. SOCIOECONOMICS

The construction and operation of a large, new underground coal mine or coal cleaning facility may cause changes in the economic and social patterns in nearby communities (Figure 66). These changes are functions of the existing patterns and the kinds of measures that are available to mitigate any adverse effects of the proposed operations.

The significance of the changes caused by a new operation normally will be greater near a small, rural community than near a large, urban area. Rural communities are likely to have a nonmanufacturing economic base, a lower per capita income, fewer social institutions, a more limited socioeconomic infrastructure, and fewer leisure pursuits than large, urban areas.

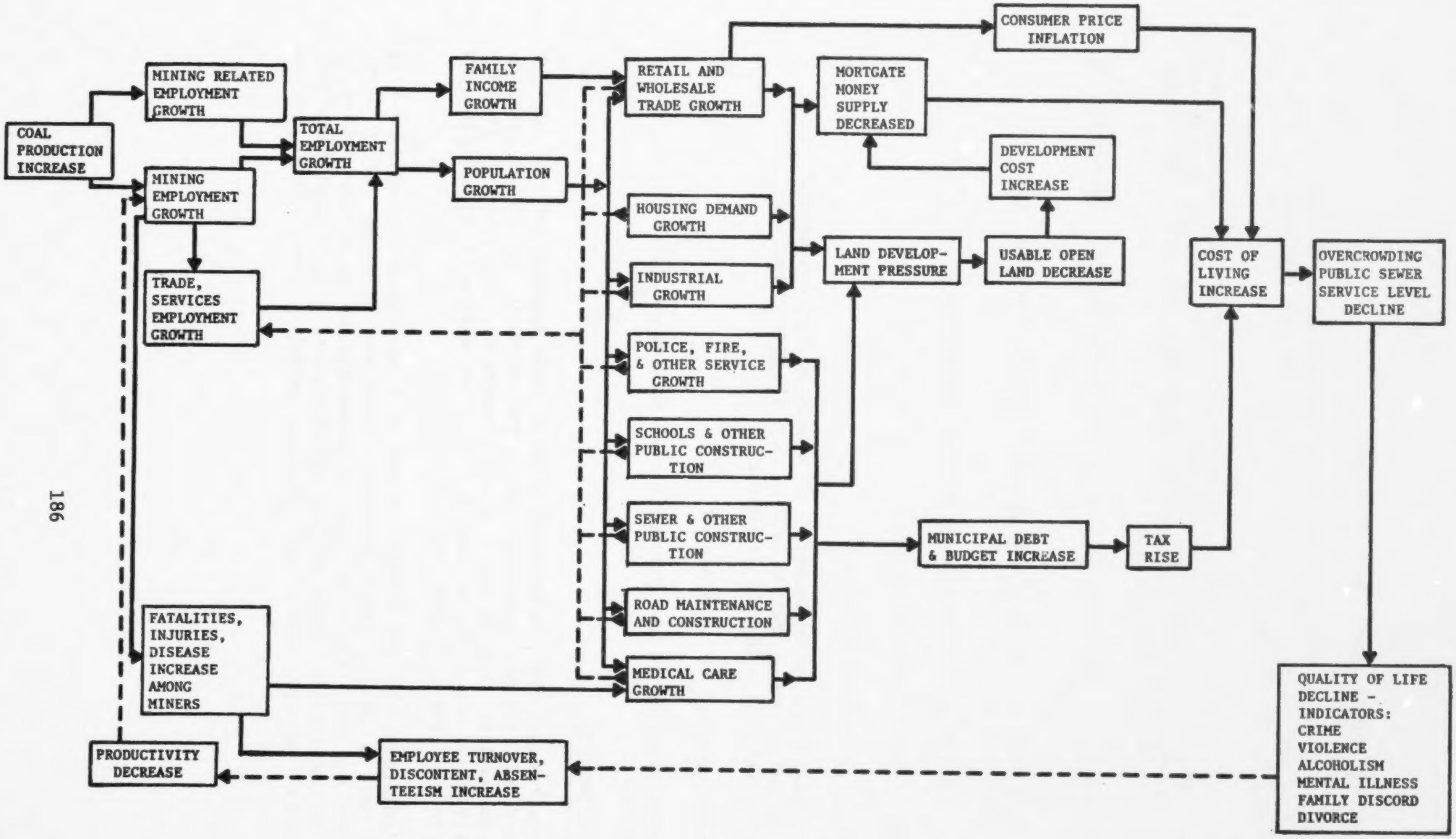

COAL PRODUCTION INCREASE
MINING RELATED EMPLOYMENT GROWTH
MINING EMPLOYMENT GROWTH
TOTAL EMPLOYMENT GROWTH
TRADE, SERVICES EMPLOYMENT GROWTH
FAMILY INCOME GROWTH
POPULATION GROWTH
RETAIL AND WHOLESALE TRADE GROWTH
HOUSING DEMAND GROWTH
INDUSTRIAL GROWTH
POLICE, FIRE, & OTHER SERVICE GROWTH
SCHOOLS & OTHER PUBLIC CONSTRUCTION
SEWER & OTHER PUBLIC CONSTRUCTION
ROAD MAINTENANCE AND CONSTRUCTION
MEDICAL CARE GROWTH
FATALITIES, INJURIES, DISEASE INCREASE AMONG MINERS
PRODUCTIVITY DECREASE
EMPLOYEE TURNOVER, DISCONTENT, ABSENTEEISM INCREASE
CONSUMER PRICE INFLATION
MORTGATE MONEY SUPPLY DECREASED
DEVELOPMENT COST INCREASE
LAND DEVELOPMENT PRESSURE
USABLE OPEN LAND DECREASE
MUNICIPAL DEBT & BUDGET INCREASE
TAX RISE
COST OF LIVING INCREASE
OVERCROWDING PUBLIC SEWER SERVICE LEVEL DECLINE
QUALITY OF LIFE DECLINE - INDICATORS:
CRIME
VIOLENCE
ALCOHOLISM
MENTAL ILLNESS
FAMILY DISCORD
DIVORCE

Figure 66. Schematic diagram of potential local socioeconomic effects on rapid expansion in coal mining. Feedback pathways are dashed.

Source: JMA. 1979. New source NPDES permits and environmental impacts of the coal mining industry in the Monongahela and Gauley river basins, West Virginia. Volume I: Coal mining environmental regulations, mining methods, and environmental impacts. Prepared for US Environmental Protection Agency Region III, Philadelphia PA, 172 p.

]

There are situations, however, in which the changes in a small community may not be significant, and conversely, in which they may be considerable in an urban area. For example, a small community may have a manufacturing (or natural resource) economic base that has declined. As a result, such a community may have a high incidence of unemployment in a skilled labor force and a surplus of housing. Conversely, a rapidly growing urban area may be severely strained if a large coal mining or cleaning operation is located nearby. The rate at which the changes occur (regardless of the circumstances) also is an important factor in determining the relative significance of the changes.

During the life of the operation, the impact will be greater if the project requires large numbers of workers to be imported temporarily from outside the community. The potentially adverse impacts include:

- Creation of social tension

- Demand for increased housing, police and fire protection, public utilities, medical facilities, recreational facilities, and other public services

- Strained economic budget in the community where existing infrastructure becomes inadequate

- Flow of local property tax revenues to municipalities other than those experiencing increased service demands as a result of the mining activity

Methods for reducing demands on the limited resources of local communities should be identified during planning for proposed operations. State and Federal programs for local assistance generally require long lead times for budgetary planning. The applicant may find it necessary to build housing and recreation facilities and provide utility services and medical facilities for an imported work force. The applicant also may prepay local taxes, and sometimes can negotiate an agreement for a corresponding reduction in the property taxes paid later. Alternatively, the communities may float bond issues, taking advantage of their tax-exempt status. The applicant may agree to reimburse the communities as payments of principal and interest become due.

The permit applicant should document fully the range of potential impacts to local communities and propose methods to minimize demands and stresses on community infrastructure. For example, an increased local tax base generally is regarded as a positive beneficial impact. The increased revenue may support the additional infrastructure required for imported employees and their families. The spending and respending of the earnings of these employees may have a multiplier effect on the local economy, as can the interindustry links created by the new operation. The community may benefit socially as the increased tax base permits the introduction of more diverse and higher quality services and the variety of community interests increases with growth in population.

In brief, the applicant's framework for analyzing the socioeconomic impacts of developing and operating an underground coal mine or coal cleaning facility should be comprehensive. The impacts should be quantified to the extent possible to assess fully the potential costs and benefits of proposed operations. The applicant should distinguish clearly between expected short-term and long-term changes. The applicant should develop and maintain close coordination with State, regional, and local planning and zoning authorities to ensure full compliance with all existing and/or proposed land use plans and other related regulations.

USEPA is developing a methodology to forecast the socioeconomic impacts of new source industries and the environmental residuals associated with those impacts.

5.0. EVALUATION OF AVAILABLE ALTERNATIVES

The purpose of an alternatives analysis is to identify and evaluate alternate plans and actions that may accomplish the desired goals of the project. These alternatives can include process modifications, site relocations, project phasing, or project cancellation. Each alternative should be evaluated equitably, on the basis of both environmental and cost-effectiveness considerations.

For the alternatives to a proposed project to be identified and evaluated properly, environmental factors should be considered early in the applicant's planning. The social, economic, and environmental factors should be defined for the evaluation of each alternative. Cost/benefit analysis is only one means by which alternatives can be compared. The environmental and social benefits of each alternative also should be considered. In general, the complexity of the alternative analyses should be a function of the magnitude and significance of the expected impacts of the proposed operations. An underground coal mining or cleaning operation that is demonstrated to have a relatively minimal impact on a region generally requires fewer alternatives to be presented in the EID.

The public's attitude toward the proposed operation and its alternatives should be evaluated carefully. Key factors such as aesthetics, community values, and land use are the subjects of public concern, and require consideration by the applicant as well as by the affected public.

5.1. ALTERNATIVE MINE LOCATION AND SITE LAYOUT

An alternatives analysis for an underground coal mine should include a detailed description of the proposed mine location, phasing of operations, site layout, and alternative configurations of mining-related facilities (haul roads, diversion ditches, sedimentation ponds, preparation plants).

The proposed mining site and alternative locations of facilities should be indicated on map(s) that show existing environmental conditions and other relevant site information. The following minimum information generally is relevant:

- Proposed and alternative mining areas
- Placement of integral components of the mining operation
- Major local centers of population (urban, high, medium, or low density)
- Surface water bodies
- Railways, highways (existing and planned), and waterways suitable for the transportation of raw materials and wastes

- Prominent topographic features (e.g., mountains, wetlands, floodplains)

- Dedicated land use areas (parks, historic sites, wilderness areas, wildlife refuge lands, testing grounds, airports, etc.)

- Other sensitive environmental areas (prime agricultural lands, historic sites, critical habitats of rare or endangered species)

- Soil characteristics

The considerations that led to the selection of the proposed site should be supported by data, including quality of the coal resource, adequacy of transportation systems, economic factors, environmental considerations, license or permit conditions, compatibility with any existing land use planning programs, and current public opinion.

Quantification, although desirable, may not be possible for all factors considered in the analysis. Under circumstances of insufficient data, qualitative and general comparative statements supported by documentation may be sufficient to support the evaluation of alternatives. Where available, experience derived from operation of other underground mines, mines in the same area, or at sites with environmentally similar characteristics may be helpful in appraising the nature of expected environmental impacts.

5.2. ALTERNATIVE MINING METHODS AND TECHNIQUES

All feasible methods and techniques for extraction of the coal resource should be examined carefully on the basis of reliability, economy, and environmental considerations. Feasible alternatives should be screened further on the basis of factors such as:

- Land, raw materials, waste generation, waste treatment, and storage requirements

- Ambient air quality and expected emission rates

- Quality of receiving waters and proposed discharges

- Water consumption rates and proposed disruption of aquifers

- Fuel consumption rates

- Capability, reliability, residuals, and energy efficiencies of proposed waste treatment systems

- Economics
- Aesthetics
- Noise generation

A tabular or matrix form of display often is helpful in comparing feasible mining alternatives. Dismissal of alternative mining methods which are not feasible should be supported by an objective explanation of the reasons for rejection.

5.3. OTHER ALTERNATIVES CONSIDERATIONS

In addition to identifying and evaluating alternative site locations, site layout configurations, and process methods, an alternatives analysis should consider the following:

- Phased or staged mining of coal to avoid subsidence or other disturbances in areas that are seasonally sensitive
- Alternative methods of access to and from the mining site
- Alternative production rates
- Alternative reclamation techniques for surface disturbed areas and coal refuse dumps (e.g., selective replacement of overburden materials, etc.)

5.4. NO-PROJECT ALTERNATIVE

In all proposals for facilities development, the applicant must consider and evaluate the impact of not construccing the proposed new source. This analysis is not unique to the development of underground coal mines and coal cleaning facilities. The no-action alternative is described in Chapter IV (Alternatives to the Proposed New Source) of Environmental Impact Assessment Guidelines for Selected New Source Industries (USEPA 1975a).

6.0. REGULATIONS OTHER THAN POLLUTION CONTROL

Several regulations apply to the construction and operation of underground coal mines and coal cleaning facilities. Federal regulations that may be pertinent to proposed operations include, but are not limited to, the following:

- Coastal Zone Management Act of 1972 (16 USC 1451 et seq.)
- The Fish and Wildlife Coordination Act of 1934, as amended (16 USC 661-666)
- USDA Agriculture Conservation Service Watershed Memorandum 108 (1971)
- Wild and Scenic Rivers Act of 1969 (16 USC 1274 et seq.)
- The Flood Control Act of 1944
- Federal Highway Act, as amended (1970)
- The Wilderness Act of 1964, as amended (16 USC 1131 et seq.)
- Endangered Species Preservation Act, as amended (1973) (16 USC 1531 et seq.)
- The National Historical Preservation Act of 1966 (16 USC 1531 et seq.)
- Executive Order 11593 (Protection and Enhancement of Cultural Environment, 16 USC 470) (Sup. 13 May 1971)
- Archaeological and Historic Preservation Act of 1974 (16 USC 469 et seq.)
- Procedures of the Council on Historic Preservation (1973) (39 FR 3367)
- Executive Order 11988 (Protection of Floodplains; replaced EO 11296, 10 August 1966)
- The Federal Coal Mine Health and Safety Act of 1977 (88 Stat. 742)
- Energy Policy and Conservation Act of 1975 (Section 102)
- Energy Conservation and Production Act of 1976 (Section 164)

- Executive Order 11990 (Protection of Wetlands; 24 May 1977)

- USEPA Policy to Protect Environmentally Significant Agricultural Lands (Draft memorandum from Douglas Costle to Assistant Administrators, Regional Administrators, and Office Directors; undated)

Table 38. Acronyms and abbreviations.

AQCR	Air quality control region
BACT	Best available control technology
CAA	The Clean Air Act; 42 USC 7401-7642, PL 95-190, as amended
CFR	Code of Federal Regulations
CWA	The Clean Water Act, also known as the Federal Water Pollution Control Act, 92-500, as amended; 33 USC _et seq_.
EID	Environmental Impact Document
EIS	Environmental Impact Statement
EO	Executive Order
FR	Federal Register
ICC	Interstate Commerce Commission
MT	Metric Ton
NAAQS	National Ambient Air Quality Standard
NEPA	National Environmental Policy Act of 1969, PL 91-190, as amended; 42 USC 4321 _et seq_.
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standard
NTIS	National Technical Information Service
PL	Public Law
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act; PL 94-580; 43 USC 6901 _et seq_.
ROM	Run-of-mine coal
ROW	Right-of-way
SIP	State Implementation Plan (for attainment of air quality)
SMCRA	Surface Mining Control and Reclamation Act of 1977, PL 95-87

Table 38. Acronyms and abbreviations (concluded).

Stat.	Statutes (of the United States)
SWM	Stanford Watershed Model
UMWA	United Mine Workers of America
UNAMAP	User's Network for Applied Modelling of Air Pollution
US	United States
USC	United States Code
USBOM	United States Bureau of Mines
USDOE	United States Department of Energy
USDOI	United States Department of the Interior
USEIA	United States Energy Information Administration
USEPA	United States Environmental Protection Agency
USOSM	United States Office of Surface Mining Reclamation and Enforcement of the United States Department of the Interior
USSCS	Soil Conservation Service (United States Department of Agriculture)

Table 39. Metric conversions

Multiply (English Units)		by	To obtain (Metric Units)	
ENGLISH UNIT	ABBREVIATION	CONVERSION	ABBREVIATION	METRIC UNIT
acre	ac	0.405	ha	hectares
acre - feet	ac ft	1233.5	cu m	cubic meters
British Thermal Unit	BTU	0.252	kg cal	kilogram - calories
British Thermal Unit/pound	BTU/lb	0.555	kg cal/kg	kilogram calories/kilogram
cubic feet/minute	cfm	0.028	cu m/min	cubic meters/minute
cubic feet/second	cfs	1.7	cu m/min	cubic meters/minute
cubic feet	cu ft	0.028	cu m	cubic meters
cubic feet	cu ft	28.32	l	liters
cubic inches	cu in	16.39	cu cm	cubic centimeters
degree Fahrenheit	F	0.555 (°F-32)*	°C	degree Centigrade
feet	ft	0.3040	m	meters
gallon	gal	3.785	l	liters
gallon/minute	gpm	0.0631	l/sec	liters/second
horsepower	hp	0.7457	kw	kilowatts
inches	in	2.54	cm	centimeters
inches of mercury	in Hg	0.03342	atm	atmospheres
pounds	lb	0.454	kg	kilograms
million gallons/day	mgd	3,785	cu m/day	cubic meters/day
mile	mi	1.609	km	kilometer
pound/square inch (gauge)	psig	(0.06805 psig + 1)*	atm	atmospheres (absolute)
square feet	sq ft	0.0929	sq m	square meters
square inches	sq in	6.452	sq cm	square centimeters
tons (short)	t	0.907	kkg	metric tons (1000 kilograms)
yard	y	0.9144	m	meters

*Actual conversion, not a multiplier

Source: McCandless, Lee C., and Robert B. Shaver. 1978. Assessment of coal cleaning technology: first annual report. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-78-150, 153 p.

Table 40. Glossary of mining-related terms.

Bench: a layer of coal; either a coal seam separated from nearby seams by an intervening layer, or one of several layers within a coal seam that is mined separately from the others; a form cut in solid rock as distinguished from one (as a terrace) cut in unconsolidated material.

Bolting: a method of roof support in which steel bolts are secured in the roof of the mined area to assure structural stability of the roof.

Bottom: the mine floor.

Bump: a local seismic disturbance caused by either partial or total failure of a portion of the roof support system of a mine.

Cat: a caterpillar tread propulsion system.

Change out: the portion of a mining cycle during which machines and ventilation facilities are repositioned to permit cutting and loading (active mining) to continue.

Chock: a square pillar used for roof support. Chocks are constructed of prop timber laid up in alternate cross layers in log-cabin style, the center being filled with waste.

Coke: a combustible material consisting of fused ash and fixed carbon of bituminous coal.

Coking coal: a bituminous coal containing about 90% carbon and suitable for the production of coke.

Continuous mining: a system of mining which employs a machine capable of cutting the coal from an exposed face in a nearly uninterrupted manner.

Conventional mining: a system of mining which entails making a relief cut, drilling the face to permit insertion of explosives, blasting the coal, and removing the coal from the mine.

Crib: see chock.

Deep-mined coal: coal which is mined from deposits covered by sedimentary deposits of soil, rock, and the like. Access to this coal is obtained by leaving the overburden in place, rather than by removal of overburden, as in surface or strip mining.

Depth of seam: vertical distance from ground surface to seam location.

Downdip: downhill succession of cuts in mining; the opposite of updip.

Floor: the upper surface of the stratum which supports the coal before it is removed by mining.

Table 40. Glossary (continued).

Gob: mine waste consisting of rubble cut from roof and floor of a mined seam. Gob also contains coal chips and coal dust not removed from the mined region. The term is also applied to waste remaining after coal is separated from raw mine output in a cleaning operation outside the mine.

Lift: the thickness of coal removed in a mining operation. Closely related to seam height for values less than 10 feet.

Longwall: a mining strategy in which coal is removed from a longwall (face) of coal in the deposit in a series of parallel cuts on the face. The length of the cut may be from 500 to 1000 feet, hence the term, longwall.

MESA: Mining Enforcement and Safety Administration, a portion of the United States Department of the Interior.

Metallurgical grade coal: coal best suited for use in production of steel - a "premium" grade of bituminous coal.

Miner: 1) a mining machine, 2) a person who mines.

OSHA: Occupational Safety and Health Administration.

Pyrite: iron sulfide (FeS_2); a lustrous yellow mineral.

Roof: the lower extreme of overburden remaining after removal of coal.

Room and Pillar system: a mining strategy in which "rooms" are cut in the coal deposit and "pillars" of coal remain to serve as roof support.

Run-of-mire: said of ore in its natural, unprocessed state; ore just as it is mined.

Seam height: thickness of the seam.

Sedimentation: settling out of solids by gravity.

Shortwall: a mining system similar to longwall.

Slurry: a very wet, highly mobile, semiviscous mixture of finely divided insoluble matter.

Steam coal: coal best suited for and used in producing steam, primarily for the generation of electric power.

Subsidence: settling of ground surface due to movement of overburden downward to occupy void space remaining after coal extraction.

Table 40. Glossary (concluded).

Top: the roof.

Tram, Tramming: transport of a mining machine from one location to another within the mine under its own motive power.

UMWA: United Mine Workers of America.

Underground coal: coal which occurs beneath substantial sedimentary deposits of soil, rock, etc. (See deep-mined coal; the terms are essentially synonymous).

Want: a pinch or thinning of a coal seam, especially as a result of tectonic movements.

Yellow boy: a yellow gelatinous precipitate resulting from neutralization of acid mine water drainage.

7.0. BIBLIOGRAPHY

In an effort to maximize reader accessibility to literature cited in this guidelines document, bibliographic information is presented in two modes:

- Citations are listed alphabetically in author-date format under subject headings which correspond to particular areas of interest in underground coal mining. Articles emphasizing more than one topic are cross-indexed under the appropriate categories. Subject headings in this portion of the bibliography include:

  COAL - GENERAL
    Formation
    Other
    Physical Properties
    Quality Control
    Reserves
    Structure

  COAL CLEANING

  COAL INDUSTRY
    Drainage Control
    Energy
    General
    Mine Seals
    Regulations
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    Socioeconomics
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  MINING GEOLOGY

  MINING SYSTEMS

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ROCK MECHANICS

SOLID WASTE
  Disposal
  General
  Quality
  Treatment

WASTEWATER
  Mine Drainage
  Sediment Ponds

- An Alphabetical listing of complete citations for works cited in this guidelines document follows the subject index.

COAL - GENERAL

Formation

Caruccio and Ferm 1974
Horne and others 1977a
Horne and others 1977b
Horne and others 1978
Howard 1969
Pedlow 1977
Smith 1975b

Other

Advani and others 1977
Gluskoter and others 1976
University of Oklahoma 1975

Physical Properties
Duba 1976
Dutcher 1978
Laine and others 1976
McCulloch and others 1974
Paciorek and others 1972

Quality Control

Caruccio 1970
Caruccio 1972
Coleman and others 1976
Cturtnick and others 1975
Donahue and Leonard 1967
Gomez and Donaven 1971
Lapham 1971
Morth and others 1970
Thompson and Benedict 1976

Reserves

Dunn and other 1971
Elliott 1973
Gorrell and others 1972
Matson and White 1975
USBOM 1975c
USBOM 1977b
USEIA 1978
USEIA 1979
Williams and others 1972

Structure

Keenan and Carpenter 1961

COAL CLEANING

Leonard and Mitchell 1968
Merritt 1978
Meyers and others 1979a
Meyers and others 1979b
McCandless and Shaver 1978
Mudd 1968
Murray 1978
Murray and Wright 1978
Nunenkamp 1976

COAL INDUSTRY

Drainage Control

Kosowski 1972
National Coal Association 1977
Parizek and Tarr 1972
USEPA 1976b
Wilson and others 1970

Energy

Neihaus 1975
Phillips 1976
USEPA 1976f

General

National Coal Association 1975
National Coal Association 1976a
National Coal Association 1976b
Trakowski 1974

Mine Seals

Miller and Thompson 1974
Penrose 1974
Wilson and others 1970

Regulations

USEPA 1975a
USEPA 1975e
USEPA 1976c
USEPA 1976d
USEPA 1976e
US Geological Survey and Bureau of Land Management 1976

COAL INDUSTRY (continued)

Transportation

Campbell and Katell 1975
Grier and others 1976
Olson 1976
Szabo 1978
USEPA 1978b

Trends

Rabbitts and Walsh 1974

EXPLORATION

Anonymous 1977
Balch and others 1975
Barron 1978
Bond and others 1968
Bond and others 1971
Carmichael 1968
Caruccio 1975
Clarke 1976
Clayton 1977
Conselman 1968
Cook 1977
Dresen and Freystatter 1976
Fowler and others 1975
Gomez and Donaven 1971
Guu 1975
Hasbrouck and Guu 1975
Horne and others 1977
Horne and others 1978
HRB-Singer Inc. 1971
Josien 1975
Konya 1972
Medlin and Coleman 1976
Melton and Ferm 1976
Muir 1976
Risser 1973
Steflay and Leighton 1977

IMPACT

Air Quality

Brookshire and others 1979
Cavanaugh 1975
Ekeley 1911
Turner 1979

Ecology

Bradshaw 1973

IMPACT (continued)

Floodplains

Pennsylvania Department of
  Environmental Resources n.d.

General

Ahmad 1974
Bisselle and others 1975
Brown and others 1977
Down and Stocks 1978
Elphic and Stokes 1975
Glass 1973
Grim and Hill 1974
Gwynn 1973
Hill 1976
Hittman Associates, Inc. 1974
Hittman Associates, Inc. 1976
Jacobsen 1976
Lake 1972
Lave 1975
Lerch and others 1972
Minear and others 1976
Minear and others 1977
Silverman 1975
Snider and others 1978
USBOM 1975b
USEPA 1974a
USEPA 1975a

Ground Effects

Bollinger 1970
Bollinger 1971
Bushnell 1974
Dunrud 1974
Dunrud 1975
Gray 1971
Gray and others 1974
Isobe and others 1977
Jones and Bellamy 1973
Kapp 1976
Kumar and Singh 1973
Mabry 1973
Morken and Whitman 1975
Pennsylvania Department of
  Environmental Resources n.d.
Powell 1973
Shadbolt 1975
Smith 1975a
USEPA 1976b
USEPA 1978a
West and others 1974

IMPACT (continued)

Models

Anonymous 1973
Carey and others 1978
Smith and Jones 1975
Trescott 1975
Trescott and Larson 1976
Trescott and others 1976

Socioeconomics

Kolbash 1975
Moore 1977
USBOM 1975a

Water Quality

Gammon 1970
Gang and Langmuir 1974
Grubb and others 1972
Herricks and Cairns 1974
Hill 1973
Lovell 1973
Olsen and Dettman 1976
Petrus 1975
Steele and Heines 1977
USEPA 1975d
USEPA 1978a
Warner 1974
Wierenga and others 1975
Zemansky and others 1975

Water Quantity

Grubb and others 1972
Konstartynowicz and Stranz 1973
Neihaus 1975
Shock 1975
Steele and Heines 1977

METHANE

Chakrabarti 1974
Conselman 1968
Deul 1964
Deul 1971
Deul 1976
Elder and Deul 1974
Kissell and others 1974
McCulloch and Deul 1973
McCulloch and others 1975a
Popp 1974
Price and others 1973

MINING GEOLOGY

Damberger and others 1975
Deul 1976
Dresen and Freystaetter 1976
Ganow 1975
Hardy 1975
Hylbert 1976
Josien 1975
Kalia 1975
Kent 1974
Leighton and Steblay 1977
McCulloch and Deul 1973
McCulloch and others 1975b
McCulloch and others 1975c
Smith 1975b
Van Besien 1977
Williamson 1967
Wright 1969
Wright 1973b

MINING SYSTEMS

Alves 1977
Bieniawski and Hustralid 1977
Chaplin and others 1972
Cummins and Given 1973
Elder and Deul 1973
Goode 1966
Grose and Nealy 1971
Hams 1976
Hardy and others 1973
Holland and Olsen 1968
Hustralid 1976
Kentucky Department for Natural Resources and Environmental Protection 1975a
Kentucky Department for Natural Resources and Environmental Protection 1975b
Legatski and Brady 1972
Legon 1974
Light 1976
McGiddy and Witfield 1974
Medlin and Coleman 1976
Moebs and Curth 1976
Morley 1973
Nunenkamp 1976
Olsen and Tandanand 1977
Pfleider n.d.
Reeves 1975
Roberts 1966
Saperstein 1974
Sisselman 1978

MINING SYSTEMS (continued)

Stassen 1977
Steblay and Leighton 1977
Stepherson and Rockaway 1976
Stewart 1975
Stewart 1977
Systems Consultants, Inc. 1978
USEPA 1975c
Von Schonfeldt 1978
Wilson and others 1970
Wright 1969
Wright 1973a
Wright 1973b

REVIEWS

Munn 1977
USEPA 1976e

ROCK MECHANICS

Advani and others 1977
Alves 1977
Arscott and Hackett 1972
Bieniawski and Hustralid 1977
Bolstead and others 1973
Bond and others 1968
Bond and others 1971
Budavari 1974
Das 1974
Dresen and Freystaetter 1976
Fowler and others 1977
Goode 1966
Hardy 1975
Hams 1976
Holland and Olsen 1968
Hustralid 1976
Kennan and Carpenter 1961
Kidybirski and Babcock 1973
Konya 1972
Roberts 1966
Shearly and Singh 1974
Stacey 1973
Su 1976
Von Schonfeldt 1978
West and others 1974
Wright 1969

SOLID WASTE

Disposal

Atwood and Casey 1973
Capp and others 1975
Cowherd 1977

SOLID WASTE (continued)

Geer 1969
Kaufmar and McCuskey 1974
Libicki 1978
USBOM 1973
USEPA 1977
US National Academy of Sciences 1975
Wahler and Associates 1978

General

Chalekode and Blackwood 1978
Chen 1976
McCartney and Whaite 1969
Miller 1972
Taylor 1972

Quality

Busch and others 1974
Caruccio 1975

Treatment

Adams and others 1972
Minnick and others 1975
Sopper and others 1975

WASTEWATER

Mine Drainage

Beers and others 1974
Cox and others 1977
Cox and others 1979
Ford 1970
Gaines and others 1972
Gleason and Russell 1976
Hill and Bates 1978
Lau and others 1970
Loy 1974
Ricca and Taiganides 1969
Ricca and Chow 1973
Rozelle 1968
Streeter 1970
Wallitt and others 1970
Wilmoth and others 1972
Wilmoth 1977
Zaval and Burns 1974

Sediment Ponds

Leung 1977

Adams, L. M., J. P. Capp, and D. W. Gillmore. 1972. Coal mine spoil and refuse bank reclamation with power plant fly ash. Mineral Waste Utilization Symposium, Proceedings Number 3:105-111.

Advani, S. H., K. Y. Lee, H. F. Wang, and Y. T. Lin. 1977. Fracture mechanics and stress analysis associated with underground coal gasification. In F. D. Wang and G. B. Clark (eds.). Energy resources and excavation technology, Proceedings of the 18th US Symposium on rock mechanics, Colorado School of Mines Press, Golden CO, p. 2As.1-2AS.6.

Ahmad, Moid V. 1974. Coal mining and its effect on water quality. Department of Biology, University of Ohio, Athens OH, 7 p.

Alves, C. A. 1977. Rock mechanics instrumentation applied to longwall. Masters Thesis, Colorado School of Mines, Golden CO, variously paged.

Aplan, F. F., and R. Hogg. 1979. Characterization of solid constituents in blackwater effluents from coal preparation plants. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-79-006, 203 p.

American Society for Testing and Materials (ASTM). 1978. 1978 Annual Book of ASTM Standards. Part 26: Gaseous fuels; coal and coke; atmospheric analysis. Philadelphia PA, 906 p.

Anonymous. 1973. How Cyprus Mines Corporation stores environmental data in computer. World Mining (US Ed.) 9(2):30-33.

Anonymous. 1977. Hydraulic mining -- a refined and growing technological art. World Coal 3(7):55.

Arscott, R. L. and P. Hackett. 1972. Influence of geological structure on failure around certain types of underground excavations. Symposium on Rock Mechanics, Proceedings Number 10:759-784.

Atwood, G. and E. F. Casey. 1973. Feasibility of returning underground coal mine wastes to mined-out areas. In Need for national policy for the use of underground space. American Society of Civil Engineers, New York NY, p. 181-185.

Baker-Wibberley & Associates, Inc. 1977. Underground mine drainage control, Snowy Creek--Laurel Run, West Virginia, feasibility study. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Center, Cincinnati OH, EPA 600/2-77-114, 131 p.

Balch, A. H., F. Rusky, M. Lepper, and S. Peterson. 1975. Use of seismic reflection method in coal seam mapping. Society of Explor. Geophysics, Annual International Meeting, Abstract number 45, p. 34-35.

Barron, K. 1978. An air injection technique for investigating the integrity of pillars and ribs in coal mines. International Journal of Rock Mechanics, Mineral Science and Geomechanical Abstracts III 15(2):69-76.

Bell, F. G. (ed.). 1975. Investigations in areas of mining subsidence. Butterworth & Co. Ltd., London GBR.

Beers, W. F., E. J. Ciolkosg, and L. T. Kardos. 1974. Soil as a medium for the renovation of acid mine drainage water. Symposium on Coal Mine Drainage, Research paper number 5:160-171.

Bieniawski, Z. T., and W. A. Hustrulid. 1977. A review of coal pillar strength formulas. Rock Mechanics III (10):107-111.

Bisselle, A., A. Binder, R. Hoberger, L. Morrow, R. Pagano, D. Parker, S. Sasfy, and R. Strieter. 1975. Resource and land investigations (RALI) program; an approach to environmental assessment with application to western coal development. Mitre Corporation, McLean VA, Report number MTR-6988, variously paged.

Bollinger, G. A. 1970. Microearthquake activity associated with underground coal-mining in Buchanon County, Virginia. Earthquake Notes 41(4):26-27.

Bollinger, G. A. 1971. Perturbation of a local microseismic regime by underground coal-mining. Virginia Journal of Science 22(3):119.

Bolstead, D. D., J. R. Alldredge, and M. A. Mahtab. 1973. Procedures used for sampling fracture orientations in an underground coal mine. US Bureau of Mines, Report investigation number 7763, 9 p.

Bond, L. O., A. W. Schmidt, and R. P. Alger. 1968. Electric log applications in coal mining and rock mechanics. Mining Engineer 20(12):46.

Bond, L. O., R. P. Alger, and A. W. Schmidt. 1971. Well log applications in coal mining and rock mechanics. In Special mining and exploration issue, Society of Mining Engineers AIME, Transactions 250(4):355-362.

Bradshaw, A. O. 1973. The ecological effects of pollutants. In Fuel and the environment. Ann Arbor Science Publications Incorporated, Ann Arbor MI, p. 123-128.

Brookshire, David S., et al. 1979. Methods development for assessing air pollution control benefits. Volume 5: Executive summary. US Environmental Protection Agency, Office of Health and Ecological Effects, Washington DC, EPA-600/5-79-001e, 23 p.

Brown, C. K., E. H. Dettman, R. A. Hinchman, J. D. Jastrow, and F. C. Kornegay. 1977. The environmental effects of using coal for generating electricity. Argonne National Laboratory, Nuclear Regulatory Commission, and Energy Research and Development Administration, Washington DC, NTIS No. PB-267 237/6 ST, 227 p.

Bucek, M. F., and J. L. Emel. 1977. Long-term environmental effectiveness of close down procedures -- eastern underground coal mines. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-77-083, 139 p.

Budavari, S. 1974. Rock mechanics aspects of the design of underground mine workings. Australia Mining 66(10):15-27.

Busch, R. A., R. R. Backer, and L. A. Atkins. 1974. Physical property data on coal waste embankment materials. US Bureau of Mines Report Investigation Number 7964, 142 p.

Bushnell, K. O. 1975. Map showing areas that correlate with subsidence events due to underground mining of the Pittsburgh and upper Freeport coal beds, Allegheny, Washington and Westmoreland Counties, Pennsylvania. US Geological Survey, miscellaneous field study map number MF-693-C, unpaged.

Campbell, T. C., and Sidney Katell. 1975. Long-distance coal transport: unit trains or slurry pipelines. US Bureau of Mines information circular 18-8690.

Capp, J. P., D. W. Gillmore, and D. G. Simpson. 1975. Coal waste stabilization by enhanced vegetation. Reports of the Polish - US Symposium, "Environmental Protection of Openpit Coal Mines", Denver CO, p. 127-136.

Carey, D. I., A. B. Crane, and D. J. Henderson. 1978. Computer programming for maximum modeling information transfer. Water Resource Bulletin 14(1):109-118.

Carmichael, V. W. 1968. Simple air-photo techniques pare North America's exploration and mining costs. Mining Engineer 20(8):27.

Caruccio, F. T. 1970. The quantification of reactive pyrite by gram size. Symposium on Coal Mine Drainage, Research paper number 3, p. 123-131.

Caruccio, F. T. 1972. Trace element distribution in reactive and inert pyrite. Symposium on Coal Mine Drainage, Research paper number 4, p. 48-54.

Caruccio, F. T. 1975. Estimating the acid potential of coal mine refuse. In Chadwick, M. J. and Goodman, G. T. (eds.). The ecology of resource degradation and renewal: the 15th Symposium of the British Ecological Society. John Wiley & Sons, New York NY, p. 197-205.

Caruccio, F. T. and J. C. Ferm. 1974. Paleoenvironment: predictor of acid mine drainage problems. Symposium on Coal Mine Drainage, Research paper number 5, p. 5-10.

Cavanaugh, G. C., et al. 1975. Potentially hazardous emissions for the extraction and processing of coal and oil. US Environmental Protection Agency, Research Triangle Park NC, EPA-650/2-75-038.

Chakrabarti, J. N. 1974. Scientific utilization of methane from coal. Journal of Mines, Metals and Fuels 22(3):77-79.

Chalekode, P. K., and T. R. Blackwood. 1978. Source assessment: coal refuse piles, abandoned mines and outcrops, state of the art. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-78-004v, 39 p.

Chaplin, E. S., R. E. Anderson, J. J. Shore, J. L. Smith, and D. M. Jassowski. 1972. Research in advanced power systems for mining safety. Aerojet Liquid Rocket Co., Sacramento CA, 269 p.

Chen, C. Y. 1976. Investigation and statistical analysis of the geotechnical properties of coal mine refuse. Doctoral Thesis, University of Pittsburgh, Pittsburgh PA, 210 p.

Chironis, N. P. (ed.). 1978. Coal age operating handbook of coal surface mining and reclamation. McGraw-Hill, Inc., New York NY, 442 p.

Chow, V. T. 1959. Open-channel hydraulics. McGraw-Hill Book Company, New York NY, 680 p.

Clarke, A. M. 1976. Seismic surveying and mine planning: their relationships and application. In Muir, W. L. G. (ed.). Coal exploration: proceedings of the first international coal exploration symposium. International Coal Exploration Symposium Proceedings III(1):158-191, 288-293.

Clayton, C. G. 1977. Applications of nuclear techniques in the coal industry. In Nuclear techniques and mineral resources: proceedings of the international symposium on nuclear techniques in exploration, extraction and processing of mineral resources, International Atomic Energy Agency Series III (464) 9200600778:85-118.

Coleman, S. L., J. HJ. Medlin, J. J. Rowe, and F. O. Simon. 1976. A comparison of the concentration of trace metals of environmental concern in lignite, bituminous coal, and anthracite. Geological Society of America Abstracts 8:818.

Conselman, Frank B. 1968. Factors in exploration for nonassociated natural gas. In Natural gases of North America, part 4. Papers of general scope. American Association of Petroleum Geologists Memoir 9.2:1983-1989.

Cook, J. C. 1977. Borehole-radar exploration in a coal seam. Geophysics 42:1254-1257.

Cowherd, David Carlton. 1977. Geotechnical characteristics of coal mine waste. In American Society of Civil Engineers. 1977. Proceedings of the conference on geotechnical practice for disposal of solid waste materials. New York NY, 885 p.

Cox, D. B., T.-Y. J. Chu, and R. J. Ruane. 1977. Quality and treatment of coal pile runoff. National Coal Association/Bituminous Coal Research Coal Conference and Expo IV, Louisville KY, variously paged.

Cox, D. B., T.-Y. Chu, and R. J. Ruane. 1979. Characterization of coal pile drainage. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-79-051, 97 p.

Cturtnicek, T. E., S. J. Rusek, and C. W. Sandy. 1975. Evaluation of low-sulfur western coal characteristics, utilization and combustion experience. Monsanto Research Corporation, Dayton OH, 549 p.

Cummins, A. B., and I. A. Given (Editors). 1973. SME mining engineering handbook. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, variously paged.

Damberger, H. H., C. T. Ledvina, J. W. Nelson, and H. F. Krausse. 1975. Analysis of geological structures that influence roof stability in room-and-pillar mines in the Heirin (no. 6) coal, Illinois. Mining Engineering 27(12):67.

Das, B. 1974. Contortional structures in coal and their effect on the mechanical properties of coal. International Journal of Rock Mechanics and Mineral Science 11:453-457.

Deul, M. 1964. Methane drainage from coal beds, a program of applied research. Rocky Mountain Coal Mining Institute, Annual meeting number 60, Denver CO, unpaged.

Deul, Maurice. 1971. Structural control of methane migration through bituminous coalbeds. Geological Society of America Abstracts 3(7):542.

Deul, M. 1976. Geologic studies as a basis for methane drainage from coalbeds. Geological Society of America Abstracts 8:836.

D'Itri, F. M. 1972. The environmental mercury problem. CRC Press, Cleveland OH.

Donahue, B. A. and J. W. Leonard. 1967. Petrography for coal mining and coal preparation part 1 and 2. Society of Mining Engineers Transactions 238(2): 147-153, 360-365.

Down, C. G., and J. Stocks. 1978. Environmental impact of mining. Applied Sciences Publishers, Ltd. London, England. 371 p.

Dresen, L., and S. Freystaetter. 1976. Rayleigh channel waves for the in-seam seismic detection of discontinuities. Journal of Geophysics 42(2):111-129.

Duba, A. 1976. The electrical conductivity of coal and coal chars. American Geophysical Union Transactions (EOS) 57:1006.

Dunn, James R., William A. Wallace, and David B. Brooks. 1971. Mineral resource valuation in the public interest. In Special mining and exploration issue, Society of Mining Engineers AIME, Transaction 250(4):280-284.

Dunrud, C. Richard. 1974. Some engineering-geologic controls on coal mine subsidence: effects of subsidence on mining, conservation of coal reserves, and on the environment. Association of Engineering Geology, Annual Meeting, Program abstractsnumber 17:23.

Dunrud, C. R. 1975. Effects of coal mine subsidence in selected mines of Utah, Colorado, and Wyoming from the viewpoint of the engineering geologist. Geological Society of America Abstracts 7:1061.

Duerbrouck, A. W. 1977. United States coal preparation practices. World Coal 3(5):24-26.

Dutcher, R. R. (ed.). 1978. Field description of coal. American Society for Testing and Materials, Philadelphia PA, STP 661, 04-661000-13, 71 p.

Dvorak, A. J., B. G. Lewis, P. C. Chee, E. H. Dettman, and others. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. US Department of the Interior, Fish and Wildlife Service, Biological Services Program, Washington DC, FWS/OBS-78-129, 260 p.

Ekeley, John B. 1911. Nature of some coal dusts and mine air from Colorado mines. Industrial Engineering Chemical Journal 3:586.

Elder, C. H., and M. Deul. 1974. Degasification of the Mary Lee Coalbed near Oak Grove, Jefferson County, Alabama by vertical borehole in advance of mining. US Bureau of Mines Report Investigation Number 7968, 21 p.

Elliott, R. E. 1973. Coal mining risks and reserves classification with discussion. Septieme Congres International de Stratigraphie et de Geologie du Carbonifere 7(2):467-477.

Elphic, L. G., and R. A. Stokes. 1975. Environmental considerations in coal mining. In P. D. Rao, and E. N. Wolff (eds.). Focus on Alaska's coal; proceedings of the University of Alaska conference. Alaska University Mineral and Industrial Research Laboratory reprint37, p. 177-181.

Ford, C. T. 1970. Selection of limestones as neutralizing agents for coal mine water. Symposium on Coal Mine Drainage, Research paper number 3, p. 27-51.

Fowler, J. C., L. A. Rubin, and W. L. Still. 1977. Detection, delineation and location of hazards using ground probing radar in coal mines. In F. D. Wang, and G. B. Clark (eds.). Energy resources and excavation technology: proceedings of the 18th U.S. symposium on rock mechanics. Colorado School of Mines Press, Golden CO, p. 4A5.1-4A5.5.

Gaines, L., R. Jasinski, and A. Gruber. 1972. Electrochemical oxidation of acid mine waters. Symposium on Coal Mine Drainage, Research paper number 4, p. 105-114.

Gammon, J. R. 1970. The effect of inorganic sediment on stream biota. Water Quality Office, US Environmental Protection Agency, Washington DC, 141 p.

Gang, M. W., and D. Langmuir. 1974. Controls on heavy metals in surface and groundwaters affected by coal mine drainage; Clarion River-Redbank Creek Watershed, Pennsylvania. In Proceedings of the Fifth Symposium on Coal Mine Drainage Research, Louisville KY.

Ganow, H. C. 1975. A geotechnical study of the squeeze problem associated with the underground mining of coal. Doctoral Thesis, University of Illinois, Urbana IL, 265p.

Geer, M. R. 1969. Disposal of solid wastes from coal mining in Washington, Oregon, and Montana. U.S. Bureau of Mines Information Circular Number 8430, 39 p.

Gilman, J. P. W., and G. M. Ruckerbauer. 1963. Metal carcinogenesis. I: Observations of the carcinogenicity of a refinery dust, cobalt oxide, and colloidal thorium dioxide. Cancer Research 22(2):152-157.

Glass, Gary B. 1973. Contrasting the effects of coal mining in Wyoming and Pennsylvania. American Association of Petroleum Geologists, Bulletin 57(5):957.

Gleason, Virginia E., and H. H. Russell. 1976. Mine drainage bibliography, 1910-1976. (Coal and the Environment Abstract Series). Bituminous Coal Research, Inc., for the US Environmental Protection Agency and Pennsylvania Department of Environmental Resources, Monroeville PA, 288 p.

Gluskoter, H. J., R. R. Rych, W. G. Miller, R. A. Cahill, G. B. Dreher, and J. K. Kuhn. 1977. Trace elements in coal: occurrence and distribution. Illinois State Geological Survey Circular 499, Urbana IL, 154 p.

Gomez, Manuel, and D. J. Donaven. 1971. Prediction of low-temperature carbonization properties of coal in advance of mining. U.S. Bureau of Mines, Washington DC, 94 p.

Goode, Claude E. 1966. A study of photoelastic coatings applied to rock models. In Symposium on rock mechanics applications in coal mines. Monongaliela Valley Coal Mining Institute and West Virginia University School of Mines, Morgantown WV, p. 78-95.

Gorrell, H. A., C. A. S. Bulmer, and M. J. Brusset. 1972. Monetary evaluation of coal properties. In Geological Conference on Western Canadian Coal, 1st proceedings: Resources Council of Alberta, Information Service, Number 60, p. 61-71.

Gray, R. E. 1971. Mine subsidence, support, and stabilization in western Pennsylvania. In Environmental geology in the Pittsburgh area. Geological Society of America, Annual Meeting, Field Trip Guidebook Number 6, p. 25-35.

Gray, R. E., J. C. Gamble, R. J. McLaren, and D. J. Roger. 1974. State of the art of subsidence control. Appalachian Regional Commission Report 73-111-2550, Washington DC, variously paged.

Grier, William F., C. F. Miller, and J. D. Womach. 1976. Demonstration of coal mine haul road sediment control techniques. Prepared for Kentucky Dept. for Natural Resources and Environmental Protection. Mayes, Sudderth and Etheredge, Inc., Lexington KY, and Environmental Systems Corp., Knoxville TN, 84 p.

Grim, Elmore C., and R. D. Hill. 1974. Environmental protection in surface mining of coal. National Environmental Research Center, Cincinnati OH, US Environmental Protection Agency, USGPO, Washington DC, EPA-670/2-74-093, 292 p.

Grose, W. L., and J. F. Nealy. 1971. Detector for discrimination of combustion reactions and the prevention of coal mine explosions. In Special mining and exploration issue, Society of Mining Engineers AIME, Transactions 250(4):284-286.

Grubb, Hayes F. and P. D. Ryder. 1972. Effects of coal mining on the water resources of the Tradewater River Basin, Kentucky. U.S. Geological Survey, Washington DC, Water supply paper number 1940, 83 p.

Guu, J. Y. 1975. Studies of seismic guided waves: the continuity of coal seams. Doctoral Thesis, Colorado School of Mines, Golden CO, 98 p.

Gwynn, Thomas A. 1973. Environmental implications of developing coal resources. American Association of Petroleum Geologists, Bulletin 57(5): 957.

Hams, A. H. 1976. The design of openings in underground coal mines. In The influence of excavation design and ground support on underground mining efficiency and costs. Australian Mining Industrial Research Association, Wallongong N.S.W. Australia, p. 81-86.

Hardy, H. R., Jr. 1975. Monitoring mechanical stability of geological structures. Earth and Mineral Science 44(7):49, 53-54.

Hardy, M. P., S. L. Crouch and C. Fairhurst. 1973. Hybrid computer analysis of seam extraction. Symposium on Rock Mechanics, Proceedings number 14, p. 749.

Harris, J. C., et al. 1979. EPA/IERL-RTP procedures for level 2 sampling and analysis of organic materials. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-79-033, 154 p.

Hasbrouck, W. P., and J. Y. Guu. 1975. Certification of coal-bed continuity using hole-to-hole seismic seam waves. Society of Explor. Geophysics, Annual International Meeting, Abstracts number 45, p. 34.

Hawley, M. E. (ed.). 1976. Coal, Part 1; social, economic, and environmental aspects. In Benchmark papers on energy. Dowden, Hutchinson & Ross, Inc. Stroudsburg PA, 3:384.

Herricks, E. E., and J. Cairns, Jr. 1974. The recovery of streams stressed by acid coal mine drainage. Symposium on Coal Mine Drainage, Research paper number 5, p. 11-24.

Heuper, W. D. 1961. Environmental carcinogenesis and cancers. Cancer Research 21:842.

Hill, R. D. 1973. Water pollution from coal mines. Paper presented at the 45th annual conference, Water Pollution Control Association of Pennsylvania, University Park PA. US Environmental Protection Agency, National Environmental Research Center, Cincinnati OH, 11 p.

Hill, R. D. 1976. EPA's environmental assessments related to mining in energy-development regions. American Geophysical Union Transactions (EOS) 57:915.

Hill, R. D., and E. R. Bates. 1978. Acid mine drainage and subsidence: Effects of increased coal utilization. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Office of Research and Development, Cincinnati OH, PB-281 092, 29 p.

Hittman Associates, Inc. 1974. Environmental impacts, efficiency, and cost of energy supply and end use Volume I. US Environmental Protection Agency, Washington DC, Council on Environmental Quality, Washington DC, and National Science Foundation, Washington DC, PB-238 734, variously paged.

Hittman Associates, Inc. 1976. Underground coal mining: an assessment of technology. Prepared for Electric Power Research Institute, Palo Alto CA, EPRI-AF-219, variously paged.

Holland, Charles T., and D. A. Olsen. 1968. Interfacial friction, moisture and coal pillar strength. Society of Mining Engineers Transactions 241(3):323-328.

Holway, Fred. 1977. Getting the handle on metallurgical coal. In: Chironis, Nicholas P., (ed). 1977. Coal age operating handbook of underground mining. McGraw-Hill, Inc., New York NY, 410 p.

Horne, J. C., J. C. Ferm, and A. D. Cohen. 1977. Depositional models in coal exploration and mine planning. American Association of Petroleum Geology, Bulletin 61:796.

Horne, J. C., J. C. Ferm, and R. A. Melton. 1978. Use of depositional models in predicting roof problems in coal mines. American Association of Petrology and Geology Bulletin 62(3):523-524.

Horne, J. C., J. R. Staub, D. Mathew, D. J. Howell, A. D. Cohen, and B. P. Bagang. 1977. Partings; origins and their significance in coal mining. Geological Society of America Abstracts 9:1025-1026.

Howard, James D. 1969. The influence of channel deposition on upper Cretaceous sedimentation and their effect on coal mining. Geological Society of America Abstracts 5:34-35.

HRB-Singer, Incorporated. 1971. Detection of abandoned underground coal mines by geophysical methods. US Environmental Protection Agency, Water Pollution Control Research Service, Number 14010EHN, 87 p.

Hustrulid, W. A. 1976. A review of coal pillar strength formulas. Rock Mechanics 8(2):115-145.

Hylbert, D. K. 1976. Development of geological structural criteria for predicting unstable mine roof rocks. Doctoral Thesis, University of Tennessee, Knoxville TN, 288 p.

Isobe, T., N. Mori, Y. Ishijiana, K. Sato, and A. Fukushimo. 1977. Measurements of ground tremors caused by working coal seams and analysis of results obtained. International Strata Control Conference 6, 13 p.

Jacobsen, J. J. 1976. Dynamic analysis of the environmental and social impacts of coal development in the eastern Powder River basin of Wyoming. Report Number BNWL-2804, 23 p.

Jones, C. J. F. P., and J. B. Bellamy. 1973. Computer prediction of ground movement due to mining subsidence. Geotechnique 23(4):515-530.

Josien, J. P. 1975. Methods of investigation in long wall faces. International Journal of Rock Mechanics and Mining Science 12(11):341-345.

Kalia, H. N. 1975. Understanding coal geology can improve underground mine productivity and safety. Mining Engineering 27(12):68.

Kapp, W. A. 1976. The characteristics of a subsidence trough over an area of underground coal mining. International Symposium of Land Subsidence, Anaheim CA, Program III (2):unpaged.

Kaufmar, Paul J., and John McCuskey. 1974. Underground storage of coal mine waste. Mineral Waste Utilization Symposium, Proceedings Number 4:274-283.

Keenan, Albert M., and R. H. Carpenter. 1961. Faults in pitching coal seams, their effects on mining. American Institute of Mining, Metallalergy and Petroleum Engineers Transactions 217:230-236.

Keller, G. E., S. J. Aresco, and J. Visman. 1968. Sampling of coal. In Leonard, J. W., and D. R. Mitchell (eds). 1968. Coal preparation. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p. 2-1 to 2-28.

Kent, Bion H. 1974. Geologic causes and possible preventions of roof fall in room and pillar coal mines. Pennsylvania Geological Survey, Information Circular Number 75, 17 p.

Kentucky Department for Natural Resources and Environmental Protection, and Northeastern Forest Experiment Station. 1975a. Research and demonstration of improved surface mining techniques in eastern Kentucky: Revegetation. Prepared for the Appalachian Regional Commission, Washington DC, Frankfort KY, 338 p.

Kentucky Department for Natural Resources and Environmental Protection, and Northeastern Forest Experiment Station. 1975b. Research and demonstration of improved surface mining techniques in eastern Kentucky: Revegetation manual. Prepared for the Appalachian Regional Commission, Washington DC, Frankfort KY, 104 p.

Kidybirski, A., and C. O. Babcock. 1973. Stress distribution and rock fracture zones in the roof of longwall face in a coal mine. Rock Mechanics 5(1):1-19.

King, D. T., and R. W. Fullerton. 1968. Dust collection. In Leonard, J. S., and D. R. Mitchell (eds). 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p 1-1 to 1-56.

Kipling, M. D., and J. A. H. Waterhouse. 1967. Cadmium and prostatic carcinoma. Lancet 1:730.

Kirschgessner, David A. 1977. Environmental regulations pertaining to coal utilization. In Fourth Symposium on Coal Utilization, National Coal Association/Bituminous Coal Research, Inc., Louisville KY, p. 30-40.

Kissell, Fred N., J. L. Banfield, R. W. Dalzell, and M. G. Zabetakis. 1974. Peak methane concentrations during coal mining. Analysis. Pittsburgh Mining Safety Research Center, US Bureau of Mines, Pittsburgh PA, 17 p.

Kolbash, R. L. 1975. A study of Appalachia's coal mining communities and associated environmental problems. Doctoral Thesis, Michigan State University, East Lansing MI, 96 p.

Konstartynowicz, E., and B. Stranz. 1973. Influence of the activity of mines on the water economy. U.S. Department of the Interior Research Report Number P.L. 480-1, 53 p.

Konya, Calvin J. 1972. Use of shaped explosive charges to investigate permeability, penetration, and fracture formation in coal, dolomite, and plexiglas. University of Missouri, Rolla MO, 112 p.

Kosowski, Z. V. 1972. Control of mine drainage from coal mine mineral wastes. Symposium on Coal Mine Drainage, Research Paper Number 4:423-424.

Kumar, R., and B. Singh. 1973. Mine subsidence investigations over a longwall working and the prediction of subsidence parameters for Indian mines. International Journal of Rock Mechanics and Mining Science 10(2):151-172.

Laine, E. F., D. L. Lager, and R. J. Lytle. 1976. Using electrical methods to monitor the physical properties of a coal seam. Transactions of the American Geophysical Union, (EOS) 57:1005.

Lake, Joe F. 1972. The environmental impact of coal mining at Black Mesa. New Mexico Geological Society, Annual Field Conference Guidebook, Number 23, 223 p.

Lapham, D. M. 1971. Trace elements in coal: potential economic sources and hazards. Pennsylvania Geology 2(6):6-7.

Lau, C. M., K. S. Shumate, and E. E. Smith. 1970. The role of bacteria in pyrite oxidation kinetics. Symposium on Coal Mine Drainage, Research Paper Number 3, p. 114-122.

Lave, Lester B. 1975. Short term health considerations regarding the choice of coal as a fuel. In Mineral resources and the environment: Appendix to Section III: Report of the panel on the implications of mineral production for health and the environment. National Academy of Science, Washington DC, p. B1-B12.

Lee, A. M., and J. R. Fraumeni. 1969. Arsenic and respiratory cancer in man: An occupational study. Journal of the National Cancer Institute 43(b): 1045-1052.

Legatski, L. Karl, and J. D. Brady. 1972. Control of dust from continuous coal mining machines. Pacific Technological Service, Santa Rosa CA, Annals of the New York Academy of Science 200:747-764.

Legan, M. A. 1974. Integrated reconstruction of coal mines. Journal of Mines, Metals and Fuels 22(5):125-127.

Leighton, F. W., and B. J. Steblay. 1977. Applications of microseismics in coal mines. Ser. Rock Soil Mechanics III, 2(3):205-229.

Lentzen, D. E., et al. 1978. IERL/RTP procedures manual: Level 1 environmental assessment (2nd ed.). US Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-78-201, 279 p.

Leonard, Joseph W., and David R. Mitchell. 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, 926 p.

Leonard, J. W. 1978. Evaluating coking coals. In Merritt, Paul C., (ed). 1978. Coal age operating handbook of coal preparation. McGraw-Hill, Inc., New York NY, 311 p.

Lerch, O. H., D. R. Maneval, and H. B. Montgomery. 1972. Mine drainage and other mining impacts as a regional development concern. Symposium on Coal Mine Drainage, Research Paper Number 4, p. 15-18.

Lessing, P., B. R. Kulander, B. D. Wilson, S. L. Dean, and S. M. Wooding. 1976. West Virginia landslides and slide-prone areas. West Virginia Environmental Geology Bulletin 15, 20 maps (scale 1:24,000).

Leung, S. S. 1977. Evaluation of four sedimentation ponds in the Hazard coal district, eastern Kentucky. Geological Society of America Abstracts 9(2):157-158.

Libicki, J. 1978. Effects of the disposal of coal waste and ashes in open pits. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Office of Research and Development, Cincinnati OH, EPA-600/7-78-067, 298 p.

Light, R. 1976. Health and safety. Mining Engineer 28(3):61.

Lohman, S. W. 1972. Groundwater hydraulics. US Geological Survey Professional Paper 708, 70 p.

Loofbourow, R. L. 1973. Groundwater and groundwater control. In Cummins, A. B., and I. A. Given (eds.). 1973. SME mining engineering handbook. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, variously paged.

Lovell, Harold F. 1973. Coal mine drainage pollution; 1973. Earth and Mineral Science 42(7):54-55.

Loy, L. D. Jr. 1974. Description of new innovative and theoretical mine drainage abatement techniques. Symposium on Coal Mine Drainage, Research Paper Number 5: 146-159.

Lucas, J. R., D. R. Maneual, and W. E. Foreman. 1968. Plant waste contaminants. In Leonard, J. W., and D. R. Mitchell (eds.). 1968. Coal preparation. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p. 17-1 to 17-54.

Mabry, Richard E. 1973. An evaluation of mine subsidence potential. Symposium on Rock Mechanics, Proceedings Number 14: 263-297.

MacCartney, J. C. and R. H. Whaite. 1969. Pennsylvania anthracite refuse: a survey of solid waste from mining and preparation. US Bureau of Mines Information Circular Number 8409, 77 p.

McCandless, Lee C., and Robert B. Shaver. 1978. Assessment of coal cleaning technology: first annual report. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-78-150, 153 p.

McClung, J. D. 1968. Breaking and crushing. In Leonard, J. W., and D. R. Mitchell (eds.). 1968. Coal Preparation. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p. 7-1 to 7-30.

McCulloch, C. M., and Maurice Deul. 1973. Geologic factors causing roof instability and methane emission problems; the lower Kittanning coalbed, Cambria County, Pennsylvania. US Bureau of Mines, Report Investigation Number 7769, 25 p.

McCulloch, C. M., Maurice Deul, and P. W. Jeran. 1974. Cleat in bituminous coalbeds. US Bureau of Mines, Report Investigation Number 7910, 25 p.

McCulloch, C. M., P. W. Jeran, and C. D. Sullivan. 1975. Geologic investigations of underground coal mining problems. US Bureau of Mines, Report Investigation Number 8022, 30 p.

McCulloch, C. J., J. R. Levine, F. N. Kissell and M. Deul. 1975. Measuring the methane content of coalbeds for resource evaluation. Geological Society of America, Abstracts 7:1194-1195.

McCulloch, C. M., W. P. Diamond, B. M. Bench, and M. Deul. 1975. Selected geologic factors affecting mining of the Pittsburgh coalbed. US Bureau of Mines, Report Investigation Number 8093, 72 p.

McDonnell, Archie J. 1978. Field estimates of aquatic plant respiration and its application to stream dissolved oxygen budgets. The Pennsylvania State University, Institute for Research on Land & Water Resources, University Park PA, 36 p.

McGiddy, T. C., and D. B. Whitfield. 1974. A computer system for the evaluation and planning of coal mines. International Symposium on the Application of Computer Mathematics to the Mineral Industry, Proceedings II (12):H1-H24.

McKee, J. E., and H. W. Wold. 1963. Water quality criteria, second edition. The Resources Agency of California, Sacramento CA, 539 p.

Maloney, Kenneth L., and others. 1978. Low-sulfur western coal use in existing small and intermediate size boilers. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park NC, EPA-600/7-78-153a, 422 p.

Martin, J. F., and E. F. Harris. 1977. Research and development programs for pollution control in mining and transport of solid fuels. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Extraction Technology Branch, Cincinnati OH, 4 p.

Martin, J. F., R. B. Scott, and R. C. Wilmoth. No Date. Water quality aspects of coal refuse utilization. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Extraction Technology Branch, Cincinnati, OH, un-paged.

Matson, T. K., and D. H. White Jr. 1975. The reserve base of coal for underground mining in the western United States. US Bureau of Mines Information Circular Number 8678, 238 p.

Medlin, J. H., and S. L. Coleman. 1976. Role of inorganic geochemistry in coal mine planning. Geological Society of America Abstracts 8:1007.

Melton, R. A., and J. C. Ferm. 1976. Precision logging of rock cores. Geological Society of America Abstract 8:1008.

Merritt, P. C. (editor). 1978. Coal age operating handbook of coal preparation. Coal Age Mining Informational Services, McGraw-Hill, Inc., New York NY, 311 p.

Meyers, R. A., M. J. Santy, W. D. Hart, L. C. McClanathan, and R. A. Orsini. 1979a. Reactor test project for chemical removal of pyritic sulfur from coal; Volume I, Final report. US Environmental Protection Agency, Office of Research and Development, Washington DC, EPA-600/7-79-013a, 277 p.

Meyers, R. A., M. J. Santy, W. D. Hart, L. C. McClanathan, and R. A. Orsini. 1979b. Reactor test project for chemical removal of pyritic sulfur from coal; Volume II. Appendices. US Environmental Protection Agency, Office of Research and Development, Washington DC, EPA-600/7-79-013b,117 p.

Michael Baker, Jr., Inc. 1975. Investigation of mining related pollution reduction activities and economic incentives in the Monongahela River basin. Prepared for the Appalachian Regional Commission, Washington DC, variously paged.

Miller, Glenn C., and Richard G. Zepp. 1979. Effects of suspended sediments on photolysis rates of dissolved pollutants. Water Research 13:453-459.

Miller, J. T., and D. R. Thompson. 1974. Seepage and mine barrier width. Symposium on Coal Mine Drainage, Research Paper Number 5: 103-127.

Miller, Louis V. 1972. A preliminary investigation of sludge refuse from Indiana coal mines. Indiana Academy of Science, Proceedings 81:246-250.

Minear, R. A., B. A. Tschantz, J. H. Rule, G. L. Vaughan, and D. E. Overton. 1976. Environmental aspects of coal production in the Appalachian region, progress report, June 1, 1975 - May 31, 1976. University of Tennessee, Appalachian Resources Project, Knoxville TN, 96 p.

Minear, R. A., B. A. Tschantz, J. H. Rule, G. L. Vaughan, D. E. Overton, and G. Briggs. 1977. Environmental aspects of coal production in the Appalachian region, progress report June 1, 1976 - May 31, 1977. Prepared for the US Energy Research and Development Administration under Contract No. E-(40)-4946, University of Tennessee, Knoxville TN, 91 p.

Mining Enforcement and Safety Administration. 1975. Final environmental statement, regulations governing the disposal of coal mine waste (30 CFR Part 77, Sections 77.215.h through 77.217). United States Department of the Interior, Washington DC, Variously paged, 230 p.

Mining Informational Services. 1977. 1977 Keystone coal industry manual. McGraw-Hill, New York NY, 782 p.

Minnick, Leonard J., C. L. Smith, and W. C. Webster. 1975. Treating coal mining refuse. I U Conversion Systems, Inc., United States 6 p.

Moebs, N. N., and E. A. Curth. 1976. Geologic and ground-control aspects of an experimental shortwall operation in the Upper Ohio Valley. US Bureau of Mines Report Investigation Number 8112, 30 p.

Monti, R. P., and P. T. Silbermann. 1974. Wastewater system alternatives: What are they...and what cost? Part IV Water and Wastes Engineering 11(6):52.

Moore, John R., R. A. Bohm, J. H. Lord, F. K. Schmidt-Bleek, and G. A. Vaughn. 1977. Economics of the private and social costs of Appalachian coal production. Prepared for the National Science Foundation, Washington DC, by the Appalachian Resources Project, University of Tennessee, Knoxville TN, 77 p.

Morken, J., and W. C. Whitman. 1975. Pioneer vegetation on various treatment of coal overburden. North Dakota Academy of Science, Proceedings 29:23.

Morley, Lloyd A. 1973. Electrical power utilization in underground coal mining. Earth and Mineral Science 42(5):33-37.

Morth, A. H., E. E. Smith, and K. S. Shumate. 1970. Pyritic systems; a mathematical model. Symposium on Coal Mine Drainage, Research Paper Number 3, p. 132-137.

Morth, A. H., and E. E. Smith. 1972. Acid mine drainage: A mathematical model. Fourth Symposium Coal Mine Drainage Res., Pittsburg PA, by Coal Industry Advisory Commission to ORSANCO, 11 p.

Morth, A. H., E. E. Smith, and D. S. Shumate. 1972. Pyritic Systems: A mathematical model. US Environmental Protection Agency, Washington DC, EPA-R2-72-002, NTIS PB-213 887, 171 p.

Muir, W. L. G. 1976. Coal Exploration: proceedings of the first international coal exploration symposiums. International Coal Exploration Symposium Proceedings III (1):664 p.

Munn, R. F. 1977. The coal industry in America; a bibliography and guide to studies. West Virginia University Library, Morgantown WV, 351 p.

Murray, W. F. 1978. The operation of a coal washery in Colorado. Engineering Mining Journal 86:1248-1250.

Murray, H. H., and S. Wright. 1978. Coal cleaning (desulfurization) by high-intensity magnetic separation. American Association of Petrology and Geology, Bulletin 62:(3):548.

National Coal Association. 1975. Coal facts 1974-1975. Washington DC, 95 p.

National Coal Association/Bituminous Coal Research, Inc. 1976a. Third symposium on coal utilization. Louisville KY, 233 p.

National Coal Association/Bituminous Coal Research, Inc. 1976b. Sixth symposium on coal mine drainage. Washington DC, 291 p.

National Coal Association/Bituminous Coal Research, Inc. 1977. Proceedings of the seventh symposium on coal mine drainage research. Washington DC, 257 p.

Neihaus, E. C. 1975. Water and energy requirements in the mining and processing of coal, including land reclamation. In Bowden, C., K. J. DeCooke, R. Holmes, E. J. McCullough, B. Seale, and D. White (eds.). Proceedings; conference on water requirements for lower Colorado River basin energy needs. University of Arizona, Tucson AZ, p. 151-164.

Nunenkamp, David C. 1976. Coal preparation environmental engineering manual. US Environmental Protection Agency, Office of Research and Development, Washington DC, EPA-600/2-76-138, 727 p.

Olsen, R. D.,and E. H. Dettmann. 1976. Preliminary results from a study of coal mining effects on water quality of the Tongue River, Wyoming. Hydrol. Water Resources of Arizona and the Southwest US 6:59-67.

Olson, James J., and Sathit Tandanand. 1977. Mechanized longwall mining, a review emphasizing foreign technology. Bureau of Mines Information Circular 8740.

Olson, R. E. 1976. Mine mouth power generation: a case history in two parts. Geological Society of America Abstracts 8:1036-1037.

Paciorek, K. L., R. H. Kratzer, and J. Kaufman. 1972. Coal mine combustion products: identification and analysis. Ultrasystems, Inc., Irvine CA, 165 p.

Parizek, R. R., and E. G. Tarr. 1972. Mine drainage pollution prevention and abatement using hydrogeological and geochemical systems. Symposium on Coal Mine Drainage, Research Paper Number 4, p. 56-82.

Pedlow, G. W., III. 1977. A peat island hypothesis for the formation of thick coal. Doctoral Thesis, University of South Carolina, Columbia SC, 181 p.

Pennsylvania Department of Environmental Resources. No Date. The development of environmental guidelines for land use policy, applicable to floodprone and mine-subsidence-prone areas in Pennsylvania. Appalachian Regional Commission Report 73-185-2563, Washington DC, 217 p.

Penrose, R. G., Jr. 1974. Limestone selection for permeable plug mine seals. Symposium on Coal Mine Drainage, Research Paper Number 5, p. 133-145.

Petrus, Carolyn A. 1975. Investigation of exit areas of ground water related to anthracite deep mines. Northeastern Section Geological Society of America Abstracts 7(1):105.

Pfleider, Eugene P. No date. Surface Mining. The American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York NY.

Phillips, Peter J., and others. 1976. Coal preparation for combustion and conversion. Gibbs & Hill Incorporated, EPRI Project 466-1.

Popp, J. T. 1974. The geological factors controlling the migration, retention, and emission of methane in the Berkley coalbed. Masters Thesis, Southern Illinois, Carbondale IL, unpaged.

Potts, C. L. 1965. Cadmium proteinuria: The health of battery workers exposed to cadmium oxide dust. Annals of Occupational Hygiene 8:55.

Powell, R. L. 1973. Coal mine subsidence problems in Indiana. Indiana Academy of Science, Proceedings 83:239.

Price, H. S., R. C. McCulloch, J. C. Edwards, and F. N. Kissell. 1973. A computer model study of methane migration in coal beds. Canadian Mining and Metallergy Bulletin 66(737):103-112.

Quarles, John. 1979. Federal regulation of new industrial plants. New Plants Report, P.O. Box 998, Ben Franklin Station, Washington DC, 241 p.

Rabbitts, F. T., and J. H. Walsh. 1974. A look at coal as a source for tomorrow's energy. Geoscience Number 1: 13-15.

Reeves, J. A. 1975. Underground mining. Mining Engineering 27(2):64B-64D.

Reeves, A. L., D. Deitch, and A. J. Vorwald. 1967. Beryllium carcinogenesis. I: Inhalation exposure of rats to beryllium sulfate aerosols. Cancer Research 27:46.

Ricca, V. T., and E. P. Taiganides. 1969. Hydrologic investigations of small watersheds in Ohio. Phase I, October 1966-July 1969. Ohio State University, Water Resources Center, Columbus OH, NTIS PB-209 928, 79 p.

Ricca, V. T., and K. Chow. 1973. Acid mine drainage quantity and quality generation model. AIME 102nd Annual Meeting, Chicago IL, 38 p.

Rieber, Michael, and S. L. Soo. 1977. Comparative coal transportation costs: an economic and engineering analysis of truck, belt, rail, barge and coal slurry, and pneumatic pipelines. Center for Advanced Computation, University of Illinois, Urbana IL, Bureau of Mines OFR 146, CAC Doc.#223.

Risser, Hubert E. 1973. Exploration and development of coal resources 1970-1975. In Future energy outlook. Colorado School of Mines Quarterly 68(2): 75-79.

Roberts, A. 1966. The determination of stress in the strata around mining excavations. Monogahela Valley Coal Mining Institute and West Virginia University School of Mines, Morgantown WV, p. 28-55.

Rozelle, R. B. 1968. Studies on the kinetics of iron (II) oxidation in mine drainage. US Department of the Interior, Federal Water Pollution Control Administration, Washington DC, 135 p.

Samuel, David E., J. R. Stauffer, C. H. Hocutt, and W. T. Mason (eds.). 1978. Surface mining and fish/wildlife needs in the eastern United States: proceedings of a symposium, 3-6 December 1978. West Virginia University and US Department of the Interior, Fish and Wildlife Service, FWS/OBS 78/81, US Government Printing Office, Washington DC, 386 p.

Sanford, R. L., T. L. Myers, and J. F. Stiehr. 1977. Directory of computer programs applicable to US mining practices and problems. US Department of the Interior, Bureau of Mines, Washington DC, PB-289 743, 545 p.

Saperstein, Lee W. 1974. Roof talk and other natural warning signals in underground coal mines. Earth and Mineral Science 43(5):37-38.

Scott, James J. 1976. Research and development priorities: Surface mining reclamation. Prepared for the US Bureau of Mines by the University of Missouri, Dept. of Mining, Petroleum, and Geological Engineering, Rolla MO, 158 p.

Shadbolt, C. H. 1975. Mining subsidence. In F. G. Bell (ed.). Investigations in areas of mining subsidence. Butterworth & Co. Ltd., London GBR, p. 109-124.

Shah, Y. M., and J. R. Burke. 1977. Inspection manual for the enforcement of new source performance standards: Coal preparation plants. US Environmental Protection Agency, Division of Stationary Source Enforcement, Washington DC, EPA 340/1-77-022, 156 p.

Shearly, P. R., and S. Singh. 1974. Estimation of pillar loads in single and contiguous seam workings. International Journal of Rock Mechanics and Mining Science 11(3):97-102.

Shock, D. A. 1975. Water requirements in the mining and processing of coal. Water Resources Symposium Number 8, Water management by the electric power industry, p. 256-269.

Shumate, K. S., E. E. Smith, V. T. Ricca, and G. M. Clark. 1976. Resources allocation to optimize mining pollution control. US Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-76-112,493 p.

Silverman, A. J. 1975. Environmental effects: assessment of energy development. In Clark, W. F. (ed.). Proceedings of the Fort Union coal field symposium; Volume 1 general session; administration section. Montana Academy of Science, Missoula MT, p. G26-G34.

Sisselman, Robert (ed.). 1978. E/MJ operating handbook of mineral underground mining. 3 vols. McGraw-Hill, Inc., New York NY.

Smith, G. E., and J. E. Jones, Jr. 1975. Will Rogers style data dissemination in an age of Buck Rogers style data acquisition: data resources for environmental impact assessment. Mining Engineering 27(12):68.

Smith, M. 1975a. Coal mine subsidence in Washington state: inventory of a geologic hazard. Geological Society of America Abstracts 7:377.

Smith, W. J. 1975b. A study of the stratigraphical and tectonic settings of a coal seam in relationship to their effect on face performance. Congr. Int. Stratigr. Geol. Carbonifer C.R. 4(7):239-251.

Snider, Henry I., Michael Gable, and R. Max Ferguson. 1978. Analysis of current land use and zoning versus selected environmental factors in drainage basins containing lakes or ponds. Research project technical completion report, Eastern Connecticut State College, OWRT Project No. A-068-CONN. 13 p.

Sopper, William E., L. T. Kardos, and L. E. Dilissio. 1975. Reclamation of anthracite coal refuse using treated municipal waste water and sludge. Pennsylvania State University, University Park PA, 183 p.

Stablay, B. J., and F. W. Leighton. 1977. Microseismic research applied to strata control problems of coal bumps and roof falls. International Strata Control Conference 6, 12 p.

Stacey, T. R. 1973. Three-dimensional finite element stress analysis applied to two problems in rock mechanics. Geomechanical Abstracts 4(4):136.

Stassen, P. 1977. Strata control in longwall workings in the past twenty-five years. International Strata Control Conference 6, variously paged.

Steele, T. D., and F. J. Heines. 1977. Water resources impacts of alternative coal development plans in the Yampa River basin, Colorado and Wyoming. American Geophysical Union Transactions EOS 58:394-395.

Steblay, B. J., and F. W. Leighton. 1977. Microseismic research applied to strata control problems of coal bumps and roof falls. International Strata Control Conference 6, 12 p.

Stepherson, R. W., and J. D. Rockaway. 1976. Pillar support in underground coal mines. Engineering, Geology, and Soils Engineering Symposium Proceedings Number 14:175-189.

Stewart, C. L. 1977. Rockmass response to longwall mining of a thick coal seam utilizing shield-type supports. Master's Thesis, Colorado School of Mines, Golden CO, variously paged.

Stewart, R. M. 1975. Mine entries; slopes and shafts. In P. D. Rao and E. N. Wolff (eds.). Focus on Alaska's coal '75; proceedings of the University of Alaska conference. Alaska University Mineral and Industrial Research Laboratory Report Number 37:65-71.

Stokinger, H. E. 1963. In F. A. Patty (ed.). Industrial hygiene and toxicology. Interscience Publishers, New York NY.

Streeter, R. C. 1970. Sulfide treatment of coal mine drainage. Symposium on Coal Mine Drainage, Research Paper Number 3: 152-168.

Su, S. C. 1976. Seismic effects of faulting in coal seams: numerical modeling. Doctoral Thesis, Colorado School of Mines, Golden CO, 267 p.

Sunderman, F. W., and A. J. Donnelly. 1965. Studies of nickel carcinogenesis in metastasizing pulmonary tumors in rats induced by the inhalation of nickel carbonyl. American Journal of Clinical Pathology 46:2037.

Systems Consultants, Incorporated. 1978. Multi-year program plan of solid fuels mining and preparation. Prepared for the Division of Solid Fuels Mining and Preparation, US Department of Energy, Arlington VA.

Szabo, Michael F. 1978. Environmental assessment of coal transportation. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-081, 141 p.

Taylor, R. K. 1972. The engineering geology of the colliery spoil heaps. Arthur Holmes Geological Society Journal 4(3)i:13-22.

Thompson, R. R., and L. G. Benedict. 1976. Evaluation of coking quality in coal mine planning. Geological Society of America Abstracts 8:1139.

Trakowski, A. C. 1974. Abandoned underground mines. Opening remarks, Interstate Mining Compact Commission spring meeting, Piestem WV, 16 May 1974. US Environmental Protection Agency, Office of Research and Development, Washington DC.

Trescott, Peter C. 1975. Documentation of finite-difference model for simulation of 3-dimensional groundwater flow. US. Geological Survey, Reston VA, open/file report 75-438, variously paged.

Trescott, P. C., and S. P. Larson. 1976. Documentation of finite-difference model for simulation of three-dimensional groundwater flow. US Geological Survey, Reston VA, open/file report 76-591 (Supplement to open/file report 75-438), 20 p.

Trescott, P. C., G. F. Pinder, and S. P. Larson. 1976. Techniques of Water-resource investigations of the United States Geological Survey, Book 7, Chapter Cl. Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments. US Department of the Interior, Geological Survey, Washington DC, 116 p.

Turner, D. B., and J. H. Novak. 1978. User's guide for RAM Volume I. Algorithm Description and Use. US Environmental Protection Agency, Environmental Sciences Research Laboratory, Research Triangle Park NC, EPA-600/8-78-016a, 70 p.

Turner, D. Bruce. 1979. Atmospheric dispersion modeling: A critical review. Journal of the Air Pollution Control Association 29(5):502-519.

University of Oklahoma. 1975. Energy alternatives: a comparative analysis. Science and Public Policy Program, Norman OK, variously paged.

US Bureau of Mines (USBOM). 1973. Methods and costs of coal refuse disposal and reclamation. US Bureau of Mines Information Circular Number 8576, 36 p.

US Bureau of Mines (USBOM). 1975a. Economic engineering analysis of US surface coal mines and effective land reclamation. US Department of Commerce, NTIS PB-2245-315/AS.

US Bureau of Mines (USBOM). 1975b. Draft environmental statement, surface subsidence control in mining regions. US Department of the Interior, Washington DC, DES-75-37, 47 p.

US Bureau of Mines (USBOM). 1975c. The reserve base of bituminous coal and anthracite for underground mining in the eastern United States. US Bureau of Mines Information Circular Number 8655, 428 p.

US Bureau of Mines (USBOM). 1977a. Advancing coal mining technology research, development, and demonstration in fiscal year 1977. US Bureau of Mines Information Circular Number 8730, 13 p.

US Bureau of Mines (USBOM). 1977b. Demonstrated coal reserve base of the United States on January 1, 1976.

US Bureau of Mines (USBOM). 1975. Noise control: Proceedings of Bureau of Mines Technology Transfer Seminar, Pittsburgh Mining and Safety Research Center, Pittsburgh PA, 113 p.

US Bureau of Mines (USBOM). 1978. Mineral commodity summaries. US Department of the Interior, Washington DC, 200 p.

US Council on Environmental Quality (CEQ). 1979. The good news about energy. Executive Office of the President, Washington DC, 55 p.

US Department of Energy (USDOE). 1978a. Federal coal leasing and 1985 and 1990 coal production forecasts. Leasing Policy Development Office, Washington DC, 139 p.

US Department of Energy (USDOE). 1978b. International coal technology summary document. Office of Technical Programs Evaluation, Washington DC, HCP/P-3885, 178 p.

US Department of Energy (USDOE). 1979a. Interim updates to 1985 and 1990 regional forecasts: working paper. Leasing Policy Development Office, Washington DC, 12 p.

US Department of Energy (USDOE). 1979b. Bituminous coal and lignite distribution calendar year 1978. Office of Energy Data and Interpretation, Washington DC, DOE/EIA-0125/4Q78, 86 p.

US Department of the Interior (USDOI). no date. Final environmental impact statement--proposed federal coal leasing program. US Government Printing Office, Washington DC, variously paged.

US Department of the Interior, (USDOI). 1978a. Permanent regulatory program implementing section 501(b) of the surface mining control and reclamation act of 1977: Draft environmental statement. Office of Surface Mining Reclamation and Enforcement, Washington DC, 296 p.

US Department of the Interior (USDOI). 1978b. Permanent regulatory program of the surface mining control and reclamation act of 1977: Draft regulatory analysis. Office of Surface Mining Reclamation and Enforcement, US Government Printing Office, Washington DC, 137 p.

US Department of the Interior (USDOI). 1979. Permanent regulatory program implementing section 501(b) of the surface mining control and reclamation act of 1977: Final Environmental Statement OSM-EIS-1 (January). Office of Surface Mining Reclamation and Enforcement, variously paged.

US Energy Information Administration (USEIA). 1979. Energy data reports: bituminous coal and lignite distribution, calendar year 1978. US Department of Energy, Washington DC, DOE/EIA-0125/4Q78, 85 p.

US Environmental Protection Agency (USEPA). 1973. Processes, procedures, and methods to control pollution from mining activities. Washington DC, DOE/EPA-430/9-73-011, 390 p.

US Environmental Protection Agency (USEPA). 1974a. Mine spoil potentials for soil and water quality. Washington DC, EPA-670/2-74-070, 302 p.

US Environmental Protection Agency (USEPA). 1974b. Background information for standards of performance: Coal preparation plants. Volume I: Proposed standards. Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Research Triangle Park NC, EPA 450/2-74-021a, 40 p.

US Environmental Protection Agency (USEPA). 1974c. Background information for standards of performance: Coal preparation plants. Volume II: Test data summary. Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Research Triangle Park NC, EPA-450/2-74-021b, 36 p.

US Environmental Protection Agency (USEPA). 1975a. Environmental impact assessment guidelines for selected new source industries. Office of Federal Activities, Washington DC, variously paged.

US Environmental Protection Agency (USEPA). 1975b. Review of mining and mining-related environmental impact statements (surface coal mining section draft). Office of Federal Activities, Washington DC, typescript, 153 p.

US Environmental Protection Agency (USEPA). 1975c. Criteria for developing pollution abatement programs for inactive and abandoned mine sites. EPA/440/9-75-008, Washington DC, 467 p.

US Environmental Protection Agency (USEPA). 1975d. Inactive and abandoned underground mines: Water pollution prevention and control. Washington DC, EPA-440/9-75-007, 338 p.

US Environmental Protection Agency (USEPA). 1975e. Coal mining point source category. Washington DC. Federal Register 40 202 48830-8.

US Environmental Protection Agency (USEPA). 1976a. Extensive overburden potentials for soil and water quality. Washington DC, EPA 600/2-76-184.

US Environmental Protection Agency (USEPA). 1976b. Erosion and sediment control, surface mining in the eastern United States, planning and design. USGPO Region 5-11, EPA-625/3-76-006, 238 p.

US Environmental Protection Agency (USEPA). 1976c. Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category. Office of Water and Hazardous Material, Washington DC, EPA 440/1-76/057-a, 288 p.

US Environmental Protection Agency (USEPA). 1976d. Quality criteria for water. Washington DC, p. 152-156.

US Environmental Protection Agency (USEPA). 1976e. Coal mining. Effluent guidelines and standards. Washington DC, Federal Register 41 94 19832-40.

US Environmental Protection Agency (USEPA). 1976f. Proceedings of the National conference on health, environmental effects, and control technology of energy use. Office of Energy, Minerals, and Industry, within the Office of Research and Development, Report 600/7-76-002, 340 p.

US Environmental Protection Agency (USEPA). 1977a. Reclamation of surface mined coal spoils. Washington DC, EPA-600/7-77-093, 57 p.

US Environmental Protection Agency (USEPA). 1977b. Elkins mine drainage pollution control demonstration project. Resource Extraction and Handling Division, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-77-090, 316 p.

US Environmental Protection Agency (USEPA). 1977c. Inspection manual for the enforcement of new source performance standards: coal preparation plants. Division of Stationary Source Enforcement, Washington DC, EPA-340/1-77-022, 156 p.

US Environmental Protection Agency (USEPA). 1978a. Acid mine drainage and subsidence: Effects of increased coal utilization. Washington DC, EPA-600/2-78-068, 29 p.

US Environmental Protection Agency (USEPA). 1978b. Environmental assessment of coal transportation. Washington DC, EPA-600/7-78-081, 141 p.

US Environmental Protection Agency (USEPA). 1978c. Site selection and design for minimizing pollution from underground coal mining operations. Washington DC, EPA-600/7-78-006, 98 p.

US Environmental Protection Agency (USEPA). 1979. Interagency program in energy-related health and environmental effects research: project status report. Health Effects Research Laboratory, Reseach Triangle Park NC, EPA-600/7-79-009, 160 p.

US Geological Survey and the Bureau of Land Management. 1976. Surface management of Federal coal resources (43 CFR 3041) and coal mining operating regulations (30 CFR 211), final environmental statement. US Department of the Interior, Washington DC, variously paged.

US Office of Technology Assessment. 1979. The direct use of coal: Prospects and problems of production and combustion. Washington DC, 411 p.

US Soil Conservation Service (USSCS). 1972. National engineering handbook: section 4, hydrology. US Department of Agriculture, Washington DC, variously paged.

US National Academy of Sciences. 1975. Underground disposal of coal mine wastes. Study Committee to Assess the Feasibility of Returning Underground Coal Mine Wastes to the Mined-Out Areas, Washington DC, 172 p.

Van Besien, A. C. 1977. Geological Engineering. Mining Engineer 29(2):p. 54 and 57.

Ven Katesan, S. 1978. Use of M-curves predict washing properties of coal. In Merritt, P. C. (ed.). 1978. Coal age operating handbook of coal preparation. Coal Age Mining Informational Services, McGraw-Hill, Inc., New York NY, p. 223-226.

Von Schonfeldt, H. A. 1978. Mining and in situ recovery. In: Limitation of rock mechanics in energy-resource recovery and development. US National Research Council, Committee for Rock Mechanics, Washington DC, Report Number NRC-AMPS-RM-78-1, p. 21-25.

Wachter, R. A., and T. R. Blackwood. 1978. Source Assessment: water pollution from coal storage areas. Prepared for Industrial Environmental Research Laboratory, US Environmental Protection Agency, Cincinnati OH, by Monsanto Research Corporation, Dayton OH, EPA-600/2-78-004m, 105 p.

Wager, W. D., and others. 1969. Comparative chronic inhalation toxicity of beryllium ores, bertrandite, and beryl, with production of pulmonary tumors by beryllium. Toxicology and Applied Pharmacology 15:10.

W. A. Wahler and Associates. 1978. Pollution control guidelines for coal refuse piles and slurry ponds. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/7-78-222, 214 p.

Waldbolt, G. L. 1973. Health effects of environmental pollutants. C. V. Mosby Company.

Wallitt, A., R. Jasinski, and B. Keilin. 1970. Silicate treatment of coal mine refuse piles. Symposium on Coal Mine Drainage, Research Paper Number 3, p. 180.

Walton, W. C. 1970. Groundwater resource evaluation. McGraw-Hill Book Company, New York NY, 664 p.

Warner, Don L. 1974. Rationale and methodology for monitoring groundwater polluted by mining activities. Prepared for US Environmental Protection Agency by General Electric Co., Santa Barbara CA, EPA-680/4-74-003, 68 01 0759, 85 p.

Weber, W. J. 1972. Physiochemical processes for water pollution control. John Wiley & Sons, Inc., New York NY, 596 p.

Wewerka, E. M., J. M. Williams, N. E. Vanderborgh, A. W. Harmon, P. Wagner, P. L. Wanek, and J. D. Olsen. 1978. Trace element characterization of coal wastes-Second Annual progress report October 1, 1976-September 30, 1977. US Environmental Protection Agency, Office of Research and Development, Washington DC, and US Department of Energy, Division of Environmental Control Technology, Washington DC, DOE LA-7360-PR, EPA-600/7-78-028a, 144 p.

West, Terry R., R. B. Jackson, and D. Johnson. 1974. Stabilization of underground coal mines prior to interstate highway construction. Birmingham Alabama. Association of Engineering Geology, Annual Meeting, Program Abstract Number 17, p. 37-38.

Wickstrom, G. 1972. Arsenic in the ecosystem of man. Work-Environment-Health 9(1): 2-8.

Wierenga, P. J., M. T. Van Gencichten, and F. W. Boyle. 1975. Transfer of boron and tritiated water through sandstone. Journal of Environmental Quality 4(1):83-87.

Williamson, Iain A. 1967. Coal mining geology. Oxford University Press, New York NY, 266 p.

Williams, G. D., G. J. Dickie, and J. Steines. 1972. Computer storage and retrieval of geologic data on coal deposits. In Geological Conference of Western Canadian Coal 1st Proceeding, Resource Council of Alberta, Information Service, Number 60: 73-84.

Wilmoth, R. C. 1977. Limestone and lime neutralization of ferrous iron acid mine drainage. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, EPA-600/2-77-101, 94 p.

Wilmoth, R. C., D. G. Mason, and M. Gupta. 1972. Treatment of ferrous iron acid mine drainage by reverse osmosis. Symposium on Coal Mine Drainage, Research Paper Number 4:115-156.

Wilmoth, R. C., and J. L. Kennedy. [No date]. Treatment options for acid mine drainage control. US Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory, Cincinnati OH, unpaged.

Wilson, Larry W., N. J. Matthews, and J. L. Stump. 1970. Underground coal mining methods to abate water pollution. State of the Art Literature Review. Coal Research Bureau, West Virginia University, Morgantown WV, 51 p.

Wright, Fred. 1969. Rock mechanics and coal mining. Mining Engineer 21 (2):112-113.

Wright, P. L. 1973a. Layout of continuous miner operations in the Smoky River Mines. Canadian Mining and Metallurgy Bulletin 66 (731):167-171.

Wright, T. 1973b. The ideal seam for longwall working. Geomechanical Abstracts 4(4): 134.

Yancey, H. F., and M. R. Geer. 1968. Properties of coal and impurities in relation to preparation. In Leonard, J. W., and D. R. Mitchell (eds.). 1968. Coal preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p. 1-1 to 1-56.

Young, G. K., and L. F. Gitto. 1967. Streamflow regulation for acid control. IBM Science Computing Symposium, Water Air Resource Management, 24 p.

Zaval, F. J., and R. A. Burns. 1974. Mine drainage pollution control demonstration grant procedures and requirements. US Environmental Protection Agency, Office of Research and Development, National Environmental Research Center, Cincinnati OH, EPA-670/2-74-003, 99 p.

Zawirsica, B., and K. Medras. 1968. Tumors and disorders in the porphyrin metabolism in rats with chronic experimantal lead poisoning. I Morphological studies. ZBL ablg. Path. Anat. 3:1.

Zemansky, G. M., T. Tilsworth, and D. J. Cook. 1975. Potential water quality impacts of Alaskan coal mining. In P. D. Rao and E. N. Wolff (eds.). Focus on Alaska's coal '75; proceedings of the University of Alaska conference, Alaska University Mineral and Industrial Research Laboratory, 37:182-189.

Zimmerman, R. E. 1968. Froth flotation. In Leonard, J. W., and D. R. Mitchell (eds.). 1968. Coal Preparation. The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York NY, p. 10-66 to 10-90.